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FERTILITY STUDIES ON SOIL TYPES

VI. THE EFFECT OF CONTINUED CROPPING IN THE GREENHOUSE ON THE POTASSIUM SUPPLYING POWER OF SOILS[1]

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ABSTRACT

In each of four successive years, oats and alfalfa were grown in the greenhouse with 4-10-0 and 4-10-10 fertilizers applied annually at the rate of 400 lb. per acre on samples of surface soil from nine farms on each of ten soil types occurring in the Ottawa district. The amounts of potassium removed by the crops decreased appreciably after the first year. The effect of applied potassium on the uptake of potassium by the crops was more pronounced after one year of cropping, but the relative effect on the different soils was quite similar for the different years of cropping.

The values for exchangeable potassium in each of the soils and for non-exchangeable potassium extracted with normal nitric acid in most of the soils were reduced significantly as a result of cropping. It was estimated from the average results that the reduction in exchangeable and non-exchangeable potassium amounted to approximately 12 and 44 per cent, respectively, of the uptake of potassium by the harvested crops.

The values for exchangeable and non-exchangeable potassium were effective in differentiating soil samples with respect to their capacity to supply potassium to the crops, only where the samples represented soils varying considerably in texture.

INTRODUCTION

Information on the potassium status of 90 samples of surface soil under study in the greenhouse and laboratory for one cropping year was given in a previous publication (1). The samples were collected from nine farms on each of ten soil types occurring in the Ottawa district. The influence of continued cropping on the potassium supplying power of these soils over a 4-year period is discussed in this paper. The yields of oats and alfalfa, the amounts of potassium removed by the crops and the amounts of exchangeable and non-exchangeable potassium extracted from the soils before and after cropping were used to evaluate the potassium supplying power of the soils.

MATERIALS AND PROCEDURE

The procedure followed in the first year of cropping in the greenhouse has been described (1). The 4-10-0 and 4-10-10 fertilizers, at the rate of 400 lb. per acre, were applied each fall prior to seeding the oats and alfalfa. In the second, third and fourth years of cropping, the treatments were replicated three times.

[1] Joint contribution from the Chemistry Division, Science Service, and the Division of Field Husbandry, Soils and Agricultural Engineering, Experimental Farms Service. Contribution No. 292, Chemistry Division.

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TABLE 1.—YIELDS OF OATS AND ALFALFA FOR THE FIRST AND FOURTH YEARS OF CROPPING WITH AND WITHOUT APPLIED POTASSIUM

(Mean yield per pot for 9 tests on each soil type; fertilizer applied at 400 lb. per acre)

Soil type	Oats				Alfalfa (air-dry)			
	First crop		Fourth crop		First crop		Fourth crop	
	4-10-0	4-10-10	4-10-0	4-10-10	4-10-0	4-10-10	4-10-0	4-10-10
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
Uplands sand	15.5	17.6	7.8	15.1	9.0	11.9	3.9	6.2
Rubicon loamy sand	17.7	19.3	7.9	16.0	8.3	14.2	4.6	6.1
Kars gravelly sandy loam	23.7	24.3	12.8	22.4	23.4	26.6	8.5	14.4
Grenville loam	26.4	27.3	14.0	18.7	18.2	20.5	9.0	13.9
Manotick sandy loam	23.9	24.0	11.8	18.3	14.8	17.5	5.6	8.5
Castor silt loam	23.3	23.1	9.4	18.2	12.7	16.0	4.7	7.7
Osgoode loam	21.7	20.9	12.7	18.2	14.7	18.5	8.4	12.6
Carp clay loam	29.3	26.8	22.0	23.3	21.9	22.1	15.0	14.8
North Gower clay loam	28.2	25.9	19.4	18.5	21.0	21.8	15.7	15.3
Rideau clay	33.3	30.2	25.2	27.2	22.6	24.7	14.1	15.9
L.S.D. (0.05)*			1.4				1.3	

* Based on pooled (potassium × farms), (years × farms), and (potassium × years × farms) interactions.

TABLE 2.—TOTAL AMOUNTS OF POTASSIUM (K) REMOVED PER POT BY OATS AND ALFALFA GROWN IN THE GREENHOUSE FOR FOUR CONSECUTIVE YEARS

(Mean values for 9 tests on each soil type; 4-10-10 treatment applied each year contained 91 mgm. K per pot)

Soil type	4-10-0 treatment				4-10-10 treatment			
	Crop year				Crop year			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th
	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.
Uplands sand	211	68	55	63	339	163	166	143
Rubicon loamy sand	158	51	55	58	326	173	165	138
Kars gravelly sandy loam	438	155	147	116	524	282	295	239
Grenville loam	459	161	159	123	592	272	272	226
Manotick sandy loam	373	123	124	98	462	233	242	196
Castor silt loam	271	80	82	53	390	186	160	155
Osgoode loam	327	146	120	114	432	278	272	233
Carp clay loam	883	503	428	410	858	589	505	515
North Gower clay loam	641	349	330	277	712	456	374	416
Rideau clay	1087	686	590	472	1070	695	648	675

L.S.D. (0.05) = 70; based on the pooled (potassium × farms), (years × farms), and (potassium × years × farms) interactions.

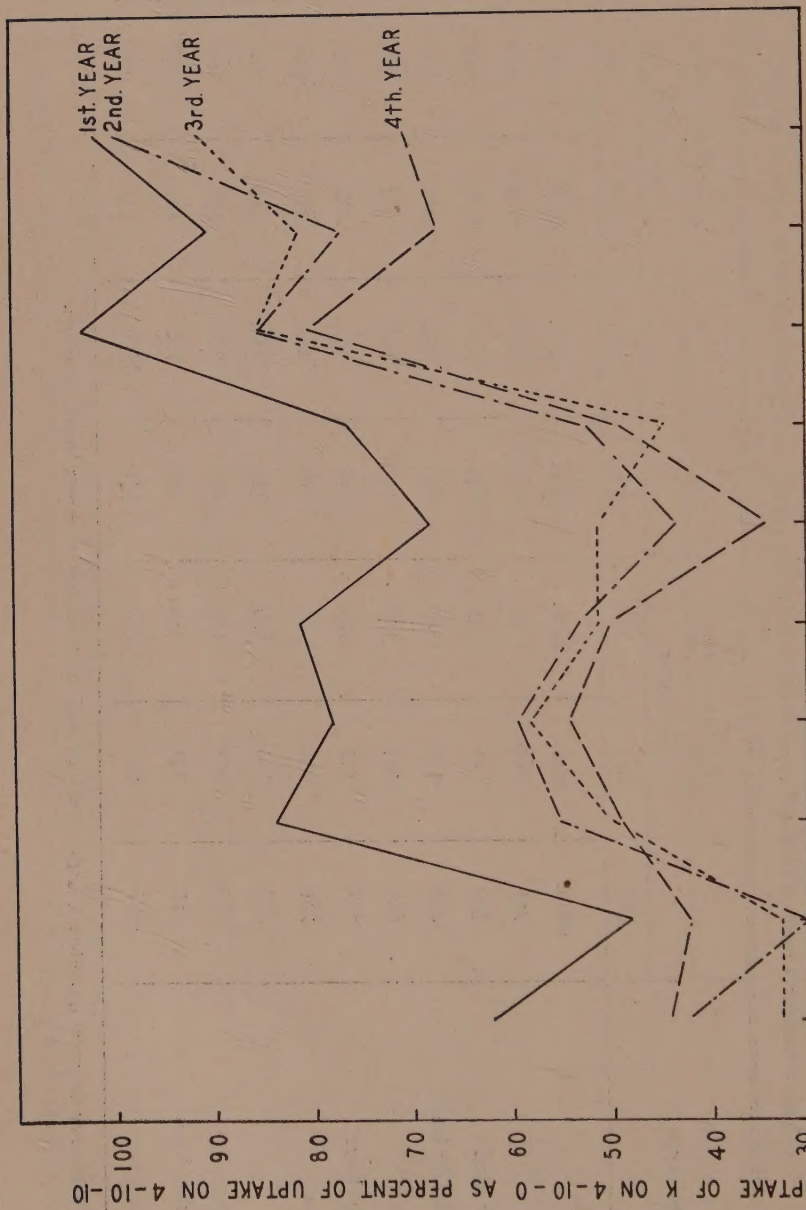

FIGURE 1. Effect of potassium applications on combined uptake of potassium by oats and alfalfa in successive years of cropping.

Yields of grain, straw, and alfalfa were obtained each year for each pot. The potassium content of each crop was determined on composite samples from all replications in each test. The potassium content of the first-year crops was determined according to the method of Garman (3). For subsequent crops, the procedure consisted of precipitation of the potassium with sodium cobaltinitrite and titration with potassium permanganate (2).

Each year, after the final cut of alfalfa, composite soil samples were taken from the pots receiving 4-10-0 fertilizer. These, as well as samples obtained prior to cropping, were analysed for exchangeable potassium, using a neutral normal ammonium acetate solution as the extractant (2). In addition, the amounts of non-exchangeable potassium in the samples taken before and after cropping were determined by extraction with 1N HNO_3 after removal of exchangeable potassium with 0.2N HNO_3 according to the procedure employed by Rouse and Bertramson (4).

RESULTS AND DISCUSSION

Yields of Oats and Alfalfa in Greenhouse

The mean yields of oats (grain plus straw) and of alfalfa, grown with and without potassium fertilizer, for the first and fourth years of cropping are presented for each soil type in Table 1. In most instances, the yields of oats and alfalfa for the fourth year of cropping were considerably lower than those obtained for the first year. Although application of potassium had no beneficial effect on the yield of oats in the first year except on Uplands sand and Rubicon loamy sand, there was a marked response to applied potassium by this crop on all but the heavier textured soils as the experiment was continued. Application of potassium (KCl) on the clay loam and clay soils resulted in a slight but significant decrease in the yield

TABLE 3.—F VALUES OBTAINED IN ANALYSES OF VARIANCE OF DATA RELATING TO UPTAKE OF POTASSIUM BY OATS AND ALFALFA

Source of variation	D.F.	Oats	Alfalfa	Oats and alfalfa
		F	F	F
Soil type	9	268.32**	260.47**	512.23**
Potassium	1	285.45**	76.18**	327.07**
Years	3	395.77**	212.28**	578.66**
Potassium × soil type	9	4.16**	1.01	1.66
Soil type × years	27	27.86**	9.21**	8.58**
Potassium × years	3	1.33	0.24	1.11
Potassium × soil type × years	27	5.27**	0.73	1.42
Farms within soil type	80	6.20**	7.42**	10.76**
Error*	560	—	—	—

* The error variances were 2971.81 for oats, 2570.73 for alfalfa, and 5684.87 for oats and alfalfa combined.

** Significant at 0.01.

of the first crop of oats but had no detrimental effect on the yield of the fourth crop. Except on Carp clay loam and North Gower clay loam, application of potassium increased the yield of alfalfa significantly. In most instances, however, the magnitude of the differences in yield of alfalfa, resulting from this relatively low rate of applied potassium, was not altered by continued cropping.

Potassium Removed by Crops

The mean values for uptake of potassium, as calculated from yield and composition data for the combined oat and alfalfa crops grown in each of four consecutive years, are presented for each soil type in Table 2. The analyses of variance for either crop (Table 3) show that the variations in the amounts of potassium removed between soil types, between potassium treatments, and between years of cropping were each highly significant. The interaction of soil type on years of cropping was highly significant as measured by the uptake of potassium by oats, alfalfa, or the two crops combined. That is, the differences in uptake of potassium occurring between soil types varied with the years of cropping. The interactions of the potassium treatment on soil type and of potassium on soil type on years of cropping were each highly significant with respect to the uptake of potassium by oats. The rate of fertilizer employed may have been too low to exert any varied effect on the uptake of potassium by alfalfa in relation to soil type.

As shown by the data in Table 2, the amounts of potassium removed by the crops grown with each of the fertilizer treatments decreased appreciably on all soils between the first and second years of cropping. The uptake of potassium by the crops in the fourth year of cropping tended to be lower than that for the second year but the differences were relatively

TABLE 4.—EFFECT OF CROPPING ON AMOUNTS OF EXCHANGEABLE POTASSIUM (K) IN THE SOILS

(Means per 100 gm. of soil for 9 farms on each soil type; 4-10-0 treatment)

Soil type	Exchangeable potassium					
	Before cropping	After cropping				L.S.D. (0.05)
		1st yr.	2nd yr.	3rd yr.	4th yr.	
	m.e.	m.e.	m.e.	m.e.	m.e.	m.e.
Uplands sand	0.09*	0.05	0.04*	0.03	0.03**	0.02
Rubicon loamy sand	0.07*	0.05	0.05	0.04	0.04*	0.01
Kars gravelly sandy loam	0.11	0.08	0.07**	0.07	0.06	0.01
Grenville loam	0.16*	0.11	0.11	0.09*	0.10	0.03
Manotick sandy loam	0.14	0.08	0.08	0.07	0.07	0.02
Castor silt loam	0.08*	0.05	0.05*	0.05	0.05	0.01
Osgoode loam	0.13	0.12	0.11	0.10	0.10	0.02
Carp clay loam	0.35	0.30	0.28	0.28	0.25	0.03
North Gower clay loam	0.36	0.30	0.28	0.26	0.24	0.04
Rideau clay	0.39	0.33	0.31	0.28	0.27	0.04

* Mean includes one value estimated statistically.

** Mean includes two values estimated statistically.

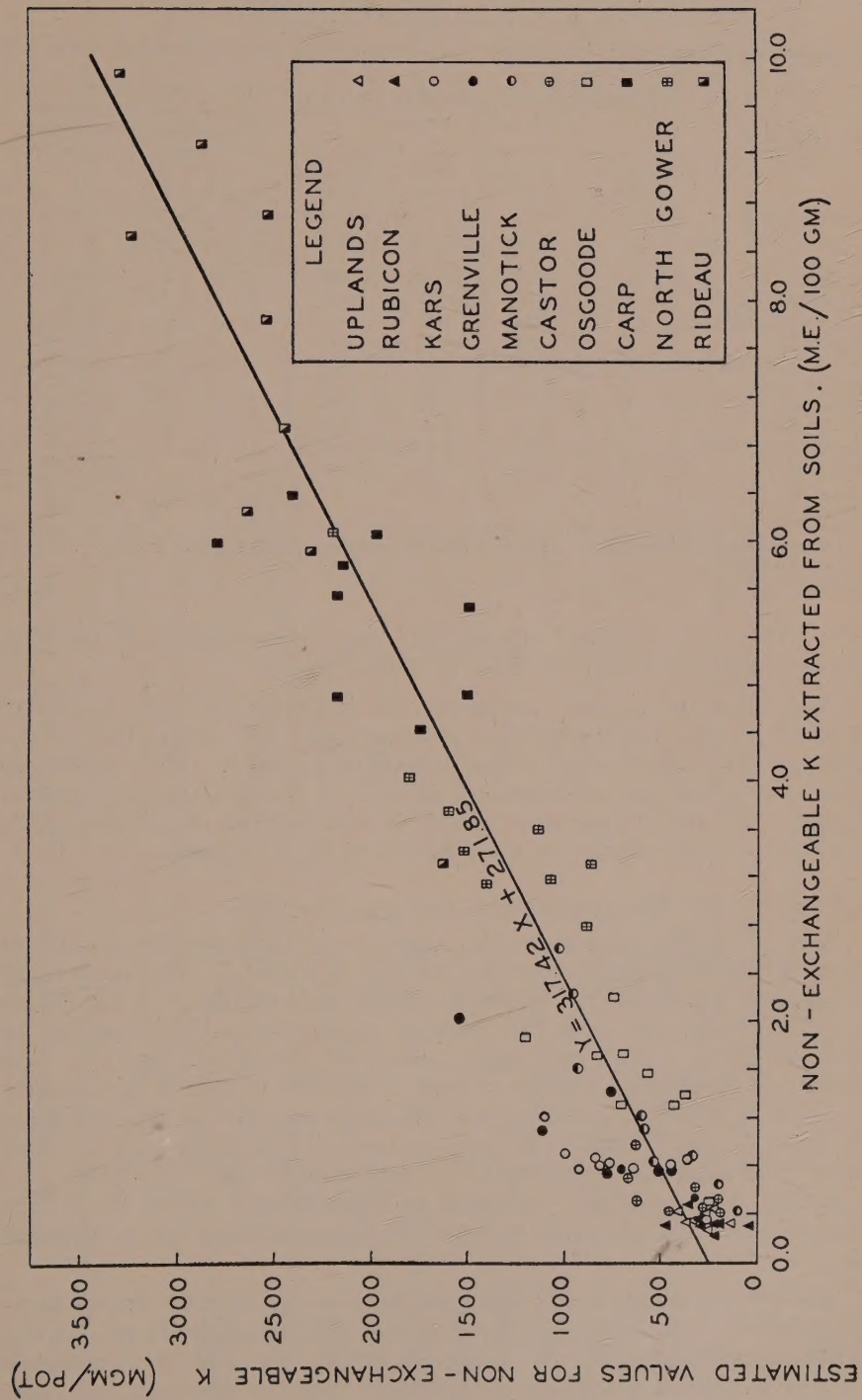

FIGURE 2. Relation of values for non-exchangeable potassium as obtained by extraction with 1N HNO_3, to those estimated from the amounts of potassium removed by the harvested crops and the associated decline in exchangeable potassium.

TABLE 5.—AMOUNTS OF NON-EXCHANGEABLE POTASSIUM EXTRACTED FROM THE SOILS, AND RELATIONSHIP BETWEEN THESE AND ESTIMATED VALUES FOR NON-EXCHANGEABLE POTASSIUM

Soil type	Non-exchangeable K extracted per 100 grams of soil; 4-10-0 treatment				Correlation between extracted and estimated amounts of non-exchangeable K before cropping[1]	
	Number of farms	Before cropping	After 4th year	L.S.D. (0.05)	D.F.	r
		m.e.	m.e.	m.e.		
Uplands sand	5	0.32	0.21	0.06	6	+0.40
Rubicon loamy sand	5	0.29	0.17	0.05	6	+0.39
Kars gravelly sandy loam	7	0.82	0.52	0.13	7	+0.54
Grenville loam	7	1.07	0.86	0.11	6	+0.87**
Manotick sandy loam	8	1.29	1.05	0.14	7	+0.94**
Castor silt loam	8	0.58	0.47	0.04	6	+0.60
Osgoode loam	8	1.52	1.40	0.26	7	+0.70*
Carp clay loam	9	5.44	4.63	0.22	7	+0.57
North Gower clay loam	8	3.81	3.52	0.17	7	+0.85**
Rideau clay	8	7.59	7.39	0.73	7	+0.89**
All soils					84	+0.96**

[1] Estimated non-exchangeable K = K removed by crops—(exchangeable K before cropping—exchangeable K after cropping).
* Significant at 0.05.
** Significant at 0.01.

slight. The crops removed considerably more potassium from the clay loam and clay soils than from those of lighter texture.

The effect of applied potassium, as indicated by the uptake of potassium on the 4-10-0 treatment expressed as a per cent of that on the 4-10-10, is illustrated for the different soils in Figure 1. The response to applied potassium was much greater on each of the soils after one year of cropping. The relative response to applied potassium on the different soils, however, was quite similar for the different years of cropping.

Exchangeable and Non-exchangeable Potassium in Soils

The effect of cropping on the amounts of exchangeable potassium extracted from the soils is shown by the data in Table 4. The amounts of exchangeable potassium in the soils varied with texture. A significant correlation coefficient (+0.75) relating the exchangeable potassium to the clay content of these soils was reported in a previous paper (1). The exchangeable potassium content of each of the soils decreased significantly as a result of cropping. The greatest decreases occurred in the clay loam and clay soils from which the highest amounts of potassium were removed by the crops. Relative to the uptake of potassium by the crops (Table 2), the decline in exchangeable potassium in Uplands sand tended to be high compared with that occurring in Carp clay loam, Rideau clay or Osgoode loam.

The average results for all soils indicated that the decrease in exchangeable potassium with cropping accounted for approximately 12 per cent of the potassium removed by the harvested crops. An analysis of variance of the exchangeable potassium data showed that the effects of soil type,

TABLE 6.—RELATIONSHIPS OF SOIL POTASSIUM VALUES AND THE POTASSIUM REMOVED BY THE CROPS

Soil type	Correlation coefficients						
	Decline of soil K versus total uptake of K on 4-10-0				Soil K before cropping versus total uptake of K on 4-10-0 as per cent of that on 4-10-10		
	D.F.	Non-exchangeable K[1]	Exchangeable K	Non-exchangeable + exchangeable K	D.F.	Non-exchangeable K	Exchangeable K
Uplands sand	3	−0.49	−0.22	−0.55	6	−0.14	−0.75*
Rubicon loamy sand	3	−0.12	+0.01	−0.08	6	−0.06	−0.53
Kars gravelly sandy loam	5	−0.63	+0.44	−0.57	7	+0.29	+0.41
Grenville loam	5	+0.72	+0.65	+0.87*	6	+0.56	+0.72*
Manotick sandy loam	6	+0.84**	+0.22	+0.80*	7	+0.82**	+0.52
Castor silt loam	6	+0.40	+0.39	+0.45	6	+0.34	+0.22
Osgoode loam	6	−0.49	+0.27	−0.49	7	+0.67	+0.71*
Carp clay loam	7	+0.03	+0.50	+0.16	7	+0.16	+0.37
North Gower clay loam	6	+0.75*	+0.32	+0.76*	7	+0.41	+0.04
Rideau clay	6	+0.16	−0.29	+0.13	7	+0.26	−0.54
All soils	71	+0.32**	+0.54**	+0.40**	84	+0.82**	+0.74**

[1] Non-exchangeable K refers to that extracted with 1N HNO_3.
* Significant at 0.05.
** Significant at 0.01.

years of cropping, and the interaction of soil type on years of cropping were each highly significant.

The amounts of non-exchangeable potassium extracted from the soils before and after cropping are presented in Table 5. Included in the table are correlation coefficients expressing the relationship between the values for non-exchangeable potassium as determined by extraction and those estimated from the amounts of potassium removed by the crops and the decline in exchangeable potassium resulting from cropping. The values for non-exchangeable potassium increased with variation in the texture of the soils from sand to clay. The correlation coefficient expressing the relationship between the amounts of non-exchangeable potassium extracted and the clay content of the soils was +0.925. This value was significant at the 1 per cent level. The amounts of non-exchangeable potassium were reduced significantly in all soils except Osgoode loam and Rideau clay as a result of cropping. The average reduction in non-exchangeable potassium was approximately 44 per cent of the amount of potassium removed by the harvested crops. As shown by the correlation coefficients in Table 5, there was a fairly good relationship between the amounts of non-exchangeable potassium extracted from the soils and corresponding estimated values for this portion of potassium. This relationship is illustrated in Figure 2.

Relationship of Soil Potassium and Greenhouse Results

Correlation coefficients expressing the relationships between the soil potassium values and the amounts of potassium removed by the crops are presented in Table 6. The decreases, as a result of cropping, in either exchangeable potassium, non-exchangeable potassium, or the two combined were not closely related to the amounts of potassium removed by the crops. The correlation coefficients expressing this relationship for the individual soil types were not significant in most instances. When computed for all soils without regard to soil type, however, the relatively low correlation coefficients were highly significant.

In only a few instances were the values for exchangeable or non-exchangeable potassium in the individual soil types correlated significantly with the uptake of potassium on the 4-10-0 treatment expressed as a percentage of that on the 4-10-10. On the basis of all soils, however, the correlation coefficients for this relationship were highly significant. Thus, the results indicate that the amounts of exchangeable or non-exchangeable potassium were effective in differentiating soil samples, with respect to their capacity to supply potassium to the crops, only where the samples represented soils varying considerably in texture.

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INFLUENCE OF THE COMPOSITION OF PARENT MATERIALS ON SOIL FORMATION IN MANITOBA[1]

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ABSTRACT

The analysis of the major horizons of ten soil profiles was undertaken in an attempt to ascertain the effect of the composition of parent material on soil formation in well-drained Mankato till sediments, under various environmental conditions. The results showed that the composition of parent materials had a profound effect on the type of profile formed. Increasing amounts of inorganic carbonates restricted profile development and inhibited the decomposition of non-calcareous rock fragments. The amount of inorganic carbonates in the parent material has been a major factor in determining and differentiating certain great soil groups; furthermore, the mineralogical composition of the parent material also has been a determining factor in the formation of Brown Podzolic and Podzol soils. Weathering of non-calcareous minerals and rocks (except shale) was found to be comparatively slight; examination of the clay fraction revealed approximately equal percentages of the dominant types in each horizon.

INTRODUCTION

The effect of the composition of soil parent materials on pedogenic processes has long been recognized. It was recorded in the well-known writings of the earlier Russian soil scientists, and it has been the subject of later researches by Polynov (7), Jenny (4), Stobbe (9), and others. Thus, the significance of parent material on soil morphological characteristics has been observed by many workers in various regions, but the extent of the influence of this factor on soil formation in Mankato till sediments that occur in the northern portion of the Central Plains Region does not appear to have been given the study which it deserves. Furthermore, owing to the fact that other soil-forming factors and processes are variables, their effect also is variable; hence, the influence of parent material in its entirety is extremely difficult to determine or to enunciate. Nevertheless, some approximations may be made from the analytical data acquired in detailed studies of the soil profiles obtained from sites where the soil-forming factors other than parent material appear to be more or less uniform.

The object of this paper is to present the results of a series of analyses dealing with the effect of parent material on the formation of soils developed under similar and under different environmental conditions. The soils were selected from well-drained sites of similar relief.

MATERIALS AND METHODS

Physical and chemical analyses were conducted on the major horizons of ten profiles which included a Dark Brown-Black Transition or Intergrade; a Blackearth; a non-calcic Blackearth; a "Northern" Blackearth; a Degrading Blackearth; a Grey Wooded; a Rendzina; a Degrading

[1] Part of thesis submitted by senior author in partial fulfilment of the requirements for the degree of Doctor of Philosophy, University of Minnesota. Joint contribution, Experimental Farms and Science Service, Canada Department of Agriculture, and Department of Soils, University of Manitoba. Contribution No. 280, Chemistry Division, Science Service, Ottawa.

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TABLE 1.—NATURE AND ENVIRONMENT OF SOILS

Type of soil	Parent Material			Environment			Soil profile
	Nature of boulder till	Texture	Carbonates as per cent $CaCO_3$	Vegetation	Climate[1]		
					P.E[2]	T-F[2]	
Dark Brown-Black Transition	Moderately calcareous	Loam	20.2	Prairie grasses	23.6	38.0	Waskada
Blackearth	Moderately calcareous	Clay loam	17.5	Tall prairie grasses	24.5	40.5	Darlingford
"Northern" Blackearth	Moderately calcareous	Clay loam	18.1	Tall prairie grasses and recent woods	25.2	34.4	Newdale
Degrading Blackearth	Moderately calcareous	Clay loam	15.1	Tall prairie grasses and deciduous woods	25.2	34.4	Erickson
Grey Wooded	Moderately calcareous	Loam	24.6	Deciduous woods—some conifers	25.2	34.4	Waitville
Rendzina	Strongly calcareous	Loam	57.4	Tall prairie grasses	26.0	38.9	Isafold
Degrading Rendzina	Strongly calcareous	Loam	65.0	Deciduous and coniferous woods	27.8	34.8	Komarno
Brown Podzolic	Non-calcareous (ferruginous)	Coarse sand	0.4	Coniferous woods—some deciduous trees	25.2	31.4	Falcon
Podzol	Non-calcareous (siliceous)	Fine sandy loam	0.1	Coniferous woods—some deciduous trees	25.2	31.4	Telford
Non-calcic Blackearth	Non-calcareous (shaly)	Clay loam	0.2	Tall prairie grasses	24.6	40.5	Manitou

[1] Climatic data are approximate; they are based on recordings of the nearest climatological station to the site of sampling.
[2] Precipitation effectiveness and temperature efficiency values are calculated according to the method used by Thornthwaite (10).

Rendzina; a Brown Podzolic and a Podzol soil. (See Table 1 and accompanying illustration). All were virgin profiles developed on materials of Mankato age, but they differed from one another in some aspect of climate, parent material or vegetative cover.

The analyses included mechanical composition, lithology of coarse fractions, mineralogical composition of clay fractions, pH values, inorganic and organic carbon and analysis of the major chemical elements. The methods have been described in detail by Ehrlich (2) and are outlined below.

Mechanical Analysis

The pipette method as described by Kilmer and Alexander (5) was followed with minor variations. Hydrogen peroxide was used as the digesting agent for the removal of organic matter, and sodium carbonate was used as the dispersing agent for the mineral fractions. Sand was separated with a 300-mesh screen, and the silt and clay in suspension were sampled with a 25-ml. pipette.

Lithology of Coarse Fractions

Approximately 4 lb. of soil were weighed and crushed with a wooden rolling-pin. The rock particles (2 to 50 mm.) were removed by sieving and weighed. The results were calculated as percentage of the original mass.

Percentages of limestone, shale and other rocks in the parent material of each profile were obtained by determining the limestone by solution with hydrochloric acid and by separating the shale and other rocks remaining as residue after treatment with acid.

Composition of Clay Fractions

Segregation of the clays was made according to the method proposed by Jackson *et al.* (3). Three clay fractions—coarse (2.0-0.2 μ), medium (0.2-0.1 μ) and fine (<0.1 μ)—were obtained from major horizons of eight profiles and each was subjected to X-ray and differential thermal analyses.

pH Values

Air-dry samples were moistened with water to a paste consistency near the lower liquid limit and the pH determined with a Coleman glass electrode apparatus.

Inorganic Carbon

Inorganic carbon was determined by decomposition of the carbonates using hydrochloric acid and absorbing the resultant carbon dioxide evolved in ascarite.

Organic Carbon

Organic carbon was estimated by subtracting inorganic carbon from total carbon. The latter was obtained by a wet combustion method which is a modification of the ones given by Adams (1) and Waynick (11).

Chemical Analysis of the Major Constituents in Soils

Silicon, iron, calcium, phosphorus and the sesquioxides were determined with methods described by Wright *et al.* (12). The method used for titanium was the one proposed by Robinson (8). Alumina was

TABLE 2.—MECHANICAL ANALYSIS, CALCIUM CARBONATE*, ORGANIC CARBON AND pH VALUES

(In per cent of oven-dry weight)

Soil profile (soil group)	Horizon	Depth (inches)	Sand 2.0-0.05 mm.	Silt 0.05-0.002 mm.	Clay <0.002 mm.	$CaCO_3$	Organic carbon	pH
Waskada	A	0- 6	43.0	36.6	20.4	0.2	4.9	7.1
(Dark Brown-Black)	B	6-13	50.7	29.0	20.4	0.6	2.0	7.3
(Transition)	Ca	13-27	42.4	37.1	20.6	24.2	0.5	7.9
	C	27-48	45.2	37.6	17.2	20.2	0.2	8.0
Darlingford	A	0-12	20.5	49.3	30.2	0.6	6.6	7.2
(Blackearth)	B	12-14	28.2	42.7	29.1	3.1	2.7	7.4
	Ca	14-25	24.8	50.1	25.1	24.4	1.0	7.9
	C	25-48	20.5	49.8	29.7	17.5	0.3	7.8
Newdale	A	0- 9	36.9	41.0	22.1	0.4	5.7	7.3
("Northern")	B	9-17	36.7	37.6	25.7	0.1	1.6	7.4
(Blackearth)	Ca	17-26	38.4	35.7	25.9	22.6	0.3	8.0
	C	26-48	43.1	36.2	20.7	18.1	0.1	8.1
Erickson	A	0- 6	29.1	43.2	27.7	0.1	7.1	7.2
(Degrading)	B_2	6-14	29.9	36.5	33.6	0.5	1.3	6.9
(Blackearth)	B_3	14-18	31.0	40.3	28.7	10.1	1.0	7.3
	Ca	18-24	34.7	38.5	26.8	18.6	0.6	7.5
	C	24-48	36.0	40.0	24.1	15.1	0.2	7.7
Waitville	A_2	0- 5	63.7	29.6	6.7	—	0.6	6.1
(Grey Wooded)	B_1	5- 9	41.3	29.3	29.3	0.1	0.6	6.0
	B_2	9-13	40.0	28.4	31.6	0.6	0.6	6.4
	B_3	13-19	45.7	29.6	24.8	10.8	0.5	7.3
	Ca	19-30	46.0	34.7	19.4	30.4	0.4	7.7
	C	30-48	44.6	36.0	19.4	24.6	0.4	7.7
Isafold	A	0- 6	42.5	44.8	12.7	4.1	7.1	7.6
(Rendzina)	C_{11}	6-14	29.5	54.0	16.5	49.8	0.8	8.0
	C_{12}	14-24	38.1	46.3	15.5	58.3	<0.1	8.4
	C_2	24-48	40.0	46.6	13.4	57.4	<0.1	8.4
Komarno	A_2	0- 2	50.6	38.1	11.3	0.3	0.9	6.8
(Degrading)	B_2	2- 5	32.6	43.3	24.2	1.3	0.7	6.6
(Rendzina)	B_3	5-14	37.7	44.4	18.0	40.1	0.4	7.6
	C_1	14-28	33.5	49.9	16.7	50.5	0.3	7.9
	C_2	28-48	62.9	28.1	9.1	65.0	0.1	8.3
Falcon	B_2	0- 6	72.5	23.6	4.0	0.6	1.3	4.5
(Brown Podzolic)	B_3	6-13	80.9	14.4	4.7	0.2	0.8	5.4
	C	13-40	87.8	8.8	3.4	0.4	0.2	5.9
Telford	A	0- 5	55.7	42.3	2.0	0.1	1.2	4.9
(Podzol)	B	5-13	57.2	40.9	1.9	0.1	0.6	5.3
	C	13-40	50.4	48.0	1.6	0.1	0.3	5.4
Manitou	A	0-17	26.6	49.8	23.6	—	4.8	6.1
(Non-calcic)	B	17-24	26.5	49.2	24.3	—	0.8	6.1
(Blackearth)	C_1	24-36	46.9	28.8	24.3	—	0.3	6.0
	C_2	36-48	46.0	32.0	22.0	0.2	0.3	6.1

* Inorganic carbon converted to calcium carbonate.

FIGURE 1

(*a*) Dark Brown-Black Transition Waskada

(*b*) Blackearth Manitou

(*c*) Blackearth Darlingford

(*d*) "Northern" Blackearth Newdale

(*e*) Degrading Blackearth Erickson

(*f*) Grey Wooded Wauville

(*g*) Rendzina Isafold

(*h*) Degrading Rendzina Komarno

(*i*) Brown Podzolic Falcon

(*j*) Podzol Telford

calculated by subtracting the sum of the oxides of iron, titanium, and phosphorus from the total of the ignited oxides. Magnesium was determined gravimetrically as magnesium pyrophosphate. The method used for manganese was that outlined by Piper (6). For sodium and potassium determinations a Beckman DU flame photometer was used on dilute HCl extracts from which organic matter and silica had been removed. In all cases, the results were expressed as the oxide of the element.

RESULTS AND DISCUSSION

Mechanical Analysis

In comparing the mechanical analysis data of the various soils and respective horizons in Table 2, it is noted that the clay content is generally higher in the sola than in the parent materials. In some profiles the difference is negligible, yet the tendency is sufficiently apparent to imply the effect of pedogenic processes.

In the Northern Blackearth, Degrading Blackearth and Grey Wooded soils developed from calcareous sediments, the quantity of clay is higher in the "B" than in the "A" horizons. It is observed that the soils, in the order of Newdale, Erickson, Komarno and Waitville profiles, show progressively greater differences in clay content between the "A" and "B" horizons. In contrast to clay translocation in these degrading calcareous types, the Falcon (Brown Podzolic) and Telford (Podzol) profiles show no significant trend of clay movement. The latter are podzolized soils which appear to be developed from primary acidic sediments rather than from decalcified materials.

Lithology of Coarse Fractions

The percentages of rock particles in each horizon and the percentages of limestone, shale and other rocks in the rock particles of the parent materials as given in Table 3 lead to two assumptions: (*a*) Either rock decomposition or disintegration has occurred in the "A" and "B" horizons of each profile, since there are fewer rock particles in these horizons than in the underlying parent material; (*b*) Limestone has weathered more rapidly than the igneous rocks, and shales have disintegrated to finer particles at a more rapid rate than the other two groups of rocks. The latter assumption is strengthened by the results obtained by Ehrlich (2) on the petrographic analysis of fine sand in these profiles.

Further examination of the data reveals that the shaly Manitou soil shows the greatest rock fragment variation from the solum to the parent material, and the Podzolic soils the least. In the others, two features are worthy of interest: *First*, more intense weathering has occurred under the prolonged influence of forest vegetation; and *second*, rock particle decomposition has been retarded and development restricted in soils that are high in limestone fragments. The Isafold (Rendzina) soil is a good example of high-lime type in which decomposition of non-calcareous rocks has been inhibited and solum thickness restricted. This soil is well drained, yet its solum is only 6 inches thick. The Komarno (Degrading Rendzina)

TABLE 3.—ROCK PARTICLES (2-50 MM.) IN THE HORIZON AND LIMESTONE, SHALE AND OTHER ROCKS IN THE PARENT MATERIALS

(Grouped according to composition of parent material)

Profile[1]	Horizon	Rock particles[2]	Limestone[3]	Shale[3]	Other rocks[3]
Waskada	A	1.6			
	B	3.9			
	Ca	5.2			
	C	6.0	49.6	8.1	42.3
Darlingford	A	2.0			
	B	3.0			
	Ca	8.5			
	C	7.7	49.7	1.4	48.9
Newdale	A	3.2			
	B	3.1			
	Ca	10.9			
	C	13.7	57.1	9.0	33.9
Erickson	A	1.4			
	B_2	2.2			
	B_3	3.7			
	Ca	7.2			
	C	6.8	51.4	9.7	38.9
Waitville	A_2	2.2			
	B_1	6.9			
	B_2	8.8			
	B_3	12.3			
	Ca	17.4			
	C	15.3	57.5	6.7	35.8
Isafold	A	6.1			
	C_{11}	9.2			
	C_{12}	13.4			
	C_2	14.3	74.8	—	25.2
Komarno	A_2	3.6			
	B_2	3.4			
	B_3	11.6			
	C_1	15.5			
	C_2	24.6	77.4	—	22.6
Falcon	B_2	25.6			
	B_3	48.6			
	C	42.3	5.4	1.4	93.2
Telford	A	3.8			
	B	10.1			
	C	8.5	2.9	0.5	96.6
Manitou	A	1.0			
	B	1.5			
	C_1	23.0			
	C_2	25.6	11.1	87.7	1.2

[1] In this and subsequent tables, the series name only is used for the sake of brevity.
[2] As per cent of horizon.
[3] As per cent of rock particles in parent material.

is another example, notwithstanding the fact that it has been under the influence of forest for a long period of time. This inverse relationship of high lime and thick solum has been frequently observed in soils by other workers.

Examination of the rock particles obtained from the site of the Brown Podzolic soil revealed that they were dominantly basaltic and schistose, high in ferromagnesian minerals. Approximately one-half of these rocks were partially weathered and in consequence were stained with limonite. From this observation it was evident that the profile developed from this type of parent material would be strongly stained with iron.

The Podzol, on the other hand, had a parent material high in silicic sediments and low in iron-bearing minerals. Although the degree of decomposition of the silicic rock materials was similar to that of the iron-bearing minerals in the Brown Podzolic, the rotted forms of the former were light in colour.

Composition of Clay Fractions

Although five distinct types of parent materials occur among the various soils investigated, only three could be identified by the mineralogical analysis of the clay fractions. This analysis does not include inorganic carbonates present in calcareous soils because they are removed by acid pretreatment in the clay segregation procedure. Furthermore, it gives no information in respect of the coarser fractions which also are of importance in the differentiation of parent materials.

From the data on the mineralogical analysis of the clay fractions reported in Tables 4, 5 and 6, it is noted that all soils except the Brown Podzolic and Podzol, are, in many respects, quite similar, the predominant minerals being montmorillonoids and illite followed by lesser quantities of feldspars, micas and quartz. In the Brown Podzolic soil, iron oxides in addition to montmorillonoid and illite minerals are the prominent components. Hematite is high in the surface horizon and goethite in the parent material. These iron compounds, common in the coarser sediments as well as in the clays, are the cause of the reddish brown coloration normal to soils in the Brown Podzolic Great Soil Group. On the basis of the iron content alone, it is obvious that this soil type contains a parent material different in composition from any of the others examined. The Podzol differs from the other soils primarily in its relatively higher content of feldspars and somewhat lower quantity of montmorillonitic and illitic clays. In this profile, as well as in the others, the prominence of feldspar and quartz in the clay fractions implies that the process of disintegration has been active.

Despite the evidence of physical disintegration, no marked decomposition or alteration of the more important minerals in the clay is indicated by the analysis. This viewpoint is supported by the equal distribution of the minerals throughout the profile. Here, kaolinization of sediments in post-glacial time has been slight, even in soils which appear to be intensely weathered. From examination in the field, both the Brown Podzolic and

TABLE 4.—MINERALOGICAL COMPOSITION[1] OF CLAY FRACTIONS IN SOILS FROM SEDIMENTS LOW IN LIME CARBONATE

Profile	Horizon	Clay fraction[2]	Montmorillonoids	Vermiculite	Chlorites	Micas	Illite	Mixed layers	Kaolinite group	Quartz	Feldspars	Al_2O_3 compounds	Hematite	Goethite	Apatite	Sepiolite	Talc	Gypsum	Palygorskite	Calcite	Others (some are not confirmed)
Manitou	A	C	—	—	2	4	2	—	—	4	3	1	—	1	—	<1	—	—	—	—	
		M	7	—	1	2	4	3	Tr	—	1	—	1	—	—	—	—	—	—	—	αCristobalite
		F	11	—	1	1	2	1	—	—	1	1	—	Tr	Tr	Tr	—	—	—	—	
	C_2	C	—	—	—	5	1	—	—	4	5	—	—	—	—	—	—	2	—	—	
		M	6	—	—	—	5	2	—	—	3	—	1	—	—	—	—	—	—	—	αCristobalite
		F	10	—	1	1	1	1	—	—	2	2	—	—	Tr	—	—	—	—	—	
Falcon	B_2	C	—	—	1	—	3	3	1	2	2	—	6	—	—	—	—	—	—	—	
		M	6	—	2	—	3	3	1	—	—	—	4	Tr	—	—	—	—	—	—	
		F	8	1	—	Tr	1	3	—	—	—	1	Tr	—	1	—	—	—	1	—	
	C	C	—	—	2	—	2	1	1	3	2	—	—	6	—	1	—	—	—	—	
		M	6	—	—	1	4	2	1	—	1	—	—	5	—	—	—	—	—	—	
		F	7	—	—	Tr	—	3	—	—	1	—	—	2	1	2	—	2	1	—	
Telford	A_2	C	2	—	1	1	3	—	1	3	4	—	1	—	—	—	—	—	?1	—	Goethite
		M	4	—	1	2	1	2	1	—	2	1	1	—	—	—	—	—	—	—	Boehmite
		F	1	1	2	—	1	2	—	—	3	2	—	—	—	—	—	1	—	—	Bayerite
	B	C	1	—	1	2	2	2	1	3	3	—	1	—	—	—	<1	—	?1	—	Boehmite
		M	2	1	1	1	—	3	1	<1	2	—	<1	—	—	—	—	—	?1	—	Bayerite
		F	3	1	1	1	1	2	<1	—	3	—	1	—	—	—	—	<1	?1	<1	αCristobalite
	C	C	—	1	2	1	3	1	1	2	2	—	1	—	—	—	—	—	—	—	Goethite
		M	2	1	2	2	1	1	1	1	1	—	—	—	—	—	—	—	—	—	Boehmite
		F	2	1	2	2	1	3	—	—	1	2	1	—	—	—	—	—	—	<1	

[1] The results are in the scale of 1-20, i.e.; 1 = 1-5 per cent, 2 = 6-10 per cent, etc.
[2] C = Coarse, M = Medium, F = Fine.

TABLE 5.—MINERALOGICAL COMPOSITION[1] OF CLAY FRACTIONS IN SOILS FROM SEDIMENTS HIGH IN LIME CARBONATE

Profile	Horizon	Clay fraction[2]	Montmorillonoids	Vermiculite	Chlorites	Micas	Illite	Mixed layers	Kaolinite group	Quartz	Feldspars	Al_2O_3 compounds	Hematite	Goethite	Apatite	Sepiolite	Talc	Gypsum	Palygorskite	Calcite	Others (some are not confirmed)
Isafold	A	C	—	—	2	2	1	—	2	4	3	2	—	2	—	—	—	1	—	—	
		M	5	—	1	—	3	2	1	—	1	3	—	—	Tr	—	—	2	—	—	Ilmenite
		F	9	—	1	1	2	4	—	—	1	—	—	—	—	—	—	—	—	—	
	C_2	C	—	—	2	2	2	—	2	5	4	2	—	1	—	—	—	—	—	—	
		M	3	—	1	2	3	4	2	—	2	3	1	—	—	—	—	—	—	—	
		F	4	—	1	—	3	4	—	—	2	—	—	—	—	—	—	—	—	2	
Komarno	A_2	C	—	—	2	3	2	—	2	7	2	—	—	—	—	—	—	—	—	—	
		M	8	—	2	2	5	—	2	—	1	—	—	—	—	—	—	—	—	—	
		F	14	—	2	—	2	—	—	—	—	—	—	—	—	—	—	—	—	1	
	B_2	C	—	—	3	3	3	—	1	6	3	—	—	—	—	—	—	—	—	—	
		M	6	—	2	2	5	—	1	—	2	—	—	1	—	—	—	—	2	—	αCristobalite
		F	12	—	—	—	2	—	—	—	—	2	—	—	—	1	—	—	—	1	
	C	C	—	—	3	—	3	—	2	6	4	—	—	—	—	—	Tr	—	—	—	
		M	5	—	3	2	5	—	1	—	3	—	—	—	—	—	—	—	—	—	
		F	5	—	—	—	2	—	—	—	3	3	—	2	Tr	1	—	—	—	—	

[1] The results are in the scale of 1-20, i.e.; 1 = 1-5 per cent, 2 = 6-10 per cent, etc.
[2] C = Coarse, M = Medium, F = Fine.

TABLE 6.—MINERALOGICAL COMPOSITION[1] OF CLAY MINERALS IN SOILS FROM SEDIMENTS MEDIUM IN LIME CARBONATE

Profile	Horizon	Clay fraction[2]	Montmorillonoids	Vermiculite	Chlorites	Hydromica	Muscovite	Illite	Mixed layers	Kaolinite group	Quartz	Feldspars	Sepiolite	Talc	Gypsum	Calcite	Others (some are not confirmed)
Darlingford	A	C	2	1	—	—	—	4	not recorded	1	4	1	—	—	—	—	not recorded
		M	10	<1	—	2	—	2		1	1	<1	1	—	—	1	
		F	10+	1	—	1	—	1		—	<1	1	1	—	1	1	
	C	C	4	—	—	1	1	5		2	5	2	—	—	—	—	
		M	8	—	—	1	1	3		2	<1	3	—	—	<1	—	
		F	10+	2	—	1	—	1		—	—	3	—	—	—	1	
Newdale	A	C	3	—	—	1	—	4	2	2	3	3	—	—	—	2	Hematite, Spinel
		M	3	<1	—	1	—	5	2	1	<1	2	—	1	—	2	Boehmite, Goethite, and Gibbsite
		F	6	—	—	1	—	4	4	—	—	2	—	—	1	—	
	B	C	2	—	—	1	—	4	2	2	4	3	—	—	—	1	Hematite, Boehmite
		M	4	1	—	1	—	7	1	1	<1	2	—	—	—	<1	Goethite and Lepidocrocite
		F	5	—	—	1	—	3	3	—	—	1	—	—	2	1	
	C	C	2	—	—	1	—	5	2	1	2	2	—	1	—	1	Bayerite, Goethite, Spinel, and Hematite
		M	2	1	—	<1	—	2	4	—	—	1	—	—	—	1	
		F	3	1	—	3	—	1	4	—	—	2	—	1	—	1	
Waitville	A_2	C	1	—	—	—	2	3	—	1	6	1	—	—	—	—	Gibbsite, Diaspore and Bayerite
		M	5	—	—	1	1	2	—	—	1	2	—	*	—	1	Goethite, Hematite and Boehmite
		F	6	1	1	2	1	1	—	—	<1	2	—	—	—	—	
	B_2	C	2	—	1	—	2	3	—	1	3	2	—	**	—	<1	Bayerite, Boehmite
		M	8	—	1	1	<1	2	1	1	1	1	—	—	—	1	Diaspore and Hematite
		F	7	—	—	1	—	2	1	—	—	1	3	—	—	—	
	C	C	1	2	1	1	—	2	—	2	5	2	—	—	—	1	Goethite and Bayerite
		M	6	—	—	3	1	1	2	2	1	3	—	—	—	—	
		F	10	—	—	1	<1	—	1	—	—	1	2	—	—	1	

[1] The results are in the scale of 1-20, i.e.; 1 = 1-5 per cent, 2 = 6-10 per cent, etc.
[2] C = Coarse, M = Medium, F = Fine.

* Weak lines.
** Strong lines.

Podzol soils appear to be intensely weathered, but the mineral analyses of their sand and clay separates do not support any such conclusion. They are, therefore, in the primary stage of weathering, and the relationship to their counterparts in more humid, warmer and older regions is morphological rather than chemical.

pH Values

The pH values of the sola in grassland soils developed from calcareous sediments indicate a high degree of base saturation. In Table 2, it is noted that the changes in reaction as affected by intensified leaching in the "A" horizon of the Degrading and Grey Wooded are not great and a high degree of base saturation is still evident. Although the carbonates are low in the surface horizons, periodic regeneration or regrading of the complex with calcium through the influence of vegetation and weathering apparently has been sufficient to maintain a high base-status.

The composition of sediments from which the soils have developed also has had a pronounced effect on the soil reaction. Soils tend to maintain a fairly constant pH as long as adequate reserves of limestone fragments are available. This is illustrated in the pH data, Table 2, in the case of soils developed from calcareous till. Changes in reaction will be gradual even under intense leaching until most of the lime has been dissolved and removed. Under grassland conditions, acidic properties may not be strongly pronounced for a long period of time after the free limestone has been dissolved in the upper portion of the soil profile, due to the replacement of calcium brought from lower levels by vegetation, and to the difficulty of removing calcium from the complex by other cations. This is demonstrated in the Manitou (non-calcic Blackearth) soil which is devoid of calcium carbonate in the solum at the present time. The Manitou soils originally were low in calcium but a sufficient quantity was available in the initial state of soil development to provide a high base status and in turn to maintain a fairly constant pH.

Inorganic Carbonates

Differentiation of parent materials on the basis of the presence or absence of lime carbonate is one of the criteria used in the classification of soils. The figures in Table 2, showing the carbonates in the soils investigated, indicate the several distinct types of parent materials. The quantities of carbonates in the "C" horizons vary from small amounts of less than 1 per cent to large amounts of over 60 per cent. With the exception of the shaly Manitou soil, it is possible to place the parent materials into three groups on the basis of their carbonate content (providing other characteristics such as texture are similar).

In the first group, a similarity in carbonate content of the parent material is noted in the Waskada, Darlingford, Newdale, Erickson and

Waitville soils. Although these show some zonal characteristics that are different from each other, they have developed from material of similar composition. In the second group, both the Isafold and Komarno soils can be placed together because of their exceptionally high carbonate content. In the last group, the Falcon and Telford can be placed together because of their very low carbonate content. However, the grouping together of the Falcon and Telford soils, which are classified as Brown Podzolic and Podzol, respectively, may be open to criticism because they differ from each other in composition of sediments other than limestone content.

The role of calcium in profile development is exceedingly important. In addition to neutralizing acidic conditions and supplying a nutrient for organisms, it has a decided effect on the type of profile that is formed under grassland or forested conditions. In grassland regions, where exceptionally high quantities of carbonates are present, the sola will be thin due to the flocculating and neutralizing effect. With decreasing amounts of carbonates, the sola, in general will be thicker. A comparison of the Manitou, Darlingford and Isafold (Blackearth-like) profiles, shown in Figure 1, emphasizes that point very strongly. In forested regions, the thickness of sola also is proportionate to the amount of carbonates present. This is shown in the Komarno (Degrading Rendzina) and Waitville (Grey Wooded) profiles.

An additional feature characteristic of forest soils, developed from sediments with appreciable amounts of lime, is the formation of typical structured and illuviated "B" horizons with finer textures than those found in the "A" horizons. This type of "B" horizon is not considered representative of Brown Podzolic or Podzol soils—although the distinction is a question of some dispute among various workers.

Organic Carbon

Variations in organic carbon content of the soils investigated are primarily attributable to local climatic conditions, to the type of native vegetation, and to the nature of the parent materials. The effect of changes in environment on this constituent is well demonstrated if the profiles found under grass are compared with those found under forest (see Table 2). However, under a similar environment, differences in organic carbon content are apparent to a lesser degree in soils developed on different parent materials.

The Manitou and Darlingford soils are influenced by similar climatic conditions but the parent materials are dissimilar. The Manitou soil has developed from non-calcareous shaly material and the Darlingford soil from somewhat finer textured sediments, high in calcareous materials. As a result of the nature of parent materials, the Manitou has a solum that is 24 inches thick and the Darlingford a solum only 14 inches thick. Notwithstanding this wide differential in solum thickness, the total carbon in the

"A" and "B" of each soil is approximately equal. In the case of the Darlingford profile with a high organic carbon content, the accumulation of organic matter is restricted to a shallower depth. The same holds true in the case of the Isafold soil. Its parent material is extremely calcareous and the organic matter is largely concentrated in the surface 6 inches. This relationship of thin profiles and high organic matter in well-drained Black-earth soils has been noted in other soils in Manitoba.

In the forested zone, the composition of parent materials will influence the nature of vegetative cover and microbial activity. For example, on the Komarno and Waitville soils which have developed from calcareous materials, the prevailing tree cover is deciduous, whereas on the Falcon and Telford soils, formed from acidic sediments, the tree cover is dominantly coniferous. In addition, there is a relationship between the quantity of available nutrients in the soil and the ash content of the vegetation produced. Consequently the composition of parent material is an important factor in modifying vegetative residues, biological processes and soil formation. Well-drained soils with an abundant supply of calcium are favourable for bacterial activity and in consequence the "A_0" tends to be composed of "mild" humus in contrast to the raw humus characteristic of the "A_0" on acid soils low in calcium. Furthermore, the organic colloids that are rendered mobile in the upper part of the profile become precipitated by calcium in the "B" horizons as they move downwards.

Chemical Analysis

The data in Table 7 show the chemical composition, by horizon depths, of the profiles previously described, and indicate the degree of weathering that has taken place. It is obvious that weathering has occurred in all soils particularly in those developed from calcareous sediments.

In the grassland soils, the weathering appears to be confined principally to the release of calcium and magnesium. Very little movement of the other elements is indicated.

Where forest is the prevailing vegetation, some of the less soluble constituents, notably iron, have been either partially translocated or have passed out of the soil in solution. In the case of soils developed from calcareous material, various constituents have been translocated but not removed, whereas the soils developed from acidic sediments, on the other hand, indicate a small loss of materials from the soil profile. As a whole, however, the weathering of sediments, other than limestone, may be considered as in the primary or early stages. This is strongly supported by mineral examination as well as by the chemical analysis data, and is particularly evident in the Falcon (Brown Podzolic) and Telford (Podzol) soils, which are under the influence of moderately acid conditions and coniferous forest vegetation, but in which the weathering of non-calcareous rocks and minerals has not advanced beyond the initial phases.

TABLE 7.—CHEMICAL ANALYSIS

(Per cent of sample after ignition)

Profile	Horizon	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	P_2O_5	MnO
Waskada	A	74.83	12.62	3.17	0.60	2.79	1.49	1.54	1.11	0.31	0.21
	B	75.56	12.56	3.25	0.56	2.09	1.62	1.66	1.36	0.23	0.17
	Ca	64.87	9.68	3.09	0.48	13.53	4.15	1.34	0.83	0.13	0.17
	C	65.81	11.42	3.34	0.32	11.49	4.60	1.32	0.94	0.18	0.16
Darlingford	A	74.30	12.82	3.58	0.35	2.90	1.75	1.69	0.82	0.25	0.32
	B	72.95	13.08	4.48	0.52	2.84	2.12	1.71	0.81	0.15	0.19
	Ca	52.47	10.77	2.28	0.41	23.08	6.89	1.38	0.64	0.19	0.10
	C	62.45	15.67	4.16	0.60	10.83	2.74	1.78	0.52	0.21	0.19
Newdale	A	76.38	11.34	3.50	0.64	2.44	1.63	1.82	1.02	0.25	0.24
	B	74.80	12.61	3.75	0.58	1.85	1.64	1.71	1.18	0.13	0.27
	Ca	65.87	10.94	2.69	0.46	12.13	3.97	1.40	0.86	0.13	0.21
	C	68.33	11.09	3.25	0.47	9.52	4.15	1.40	0.86	0.15	0.17
Erickson	A	74.10	13.20	3.75	0.62	2.67	1.56	1.86	0.87	0.30	0.30
	B_2	73.72	14.34	3.99	0.54	1.98	1.83	1.93	0.89	0.11	0.27
	B_3	68.97	12.96	4.32	0.55	6.67	2.62	1.61	0.78	0.19	0.19
	Ca	66.40	10.98	3.58	0.56	10.85	3.29	1.45	0.74	0.16	0.19
	C	69.00	10.79	3.75	1.08	8.01	3.22	1.40	0.74	0.22	0.24
Waitville	A_2	82.51	8.65	1.87	0.42	1.57	0.70	1.47	1.36	0.11	0.30
	B_1	75.80	12.73	4.64	0.60	1.22	1.72	1.82	1.11	0.05	0.30
	B_2	73.87	12.62	5.62	0.50	2.03	1.61	1.72	1.09	0.08	0.19
	B_3	72.13	10.01	5.79	0.36	4.48	3.30	1.47	1.00	0.26	0.21
	Ca	61.36	8.53	2.85	0.42	18.99	3.57	1.15	1.11	0.07	0.17
	C	65.31	10.18	3.10	0.40	13.27	3.68	1.26	1.03	0.04	0.27
Isafold	A	67.88	14.02	4.32	0.51	4.82	3.39	1.86	1.37	0.07	0.21
	C_{11}	43.41	17.41	2.85	0.36	21.31	11.19	1.41	1.00	0.10	0.13
	C_{12}	39.88	11.52	1.96	0.31	27.53	15.17	1.19	1.23	0.09	0.10
	C_2	43.91	9.59	1.30	0.14	25.37	15.52	1.27	1.21	0.06	0.10
Komarno	A_2	76.16	11.47	2.93	0.25	3.19	1.34	1.59	1.53	0.11	0.21
	B_2	66.78	18.83	4.13	0.54	1.74	3.25	1.96	1.20	0.08	0.17
	B_3	49.69	13.05	3.83	0.42	16.61	12.74	1.55	0.89	0.17	0.17
	C_1	47.99	11.38	3.34	0.26	20.73	13.35	1.13	0.71	0.10	0.13
	C_2	43.92	6.13	1.38	0.21	27.75	16.89	0.72	0.71	0.07	0.10
Falcon	B_2	64.77	13.73	14.18	1.02	1.39	1.12	1.53	1.10	0.24	0.13
	B_3	61.95	11.93	18.82	1.13	1.27	1.38	1.40	1.00	0.18	0.07
	C	60.13	11.71	21.10	0.65	1.16	1.51	1.37	0.99	0.16	0.07
Telford	A	76.07	11.81	2.44	0.42	2.96	1.31	1.80	2.06	0.03	0.16
	B	74.03	13.21	3.50	0.43	2.32	1.60	1.82	2.18	0.02	0.16
	C	73.57	12.78	3.83	0.40	2.90	1.51	1.84	2.18	0.03	0.10
Manitou	A	78.24	10.89	3.17	0.55	1.96	1.56	1.34	0.74	0.21	0.32
	B	78.11	11.70	3.25	0.32	1.45	1.54	1.47	0.82	0.12	0.24
	C_1	81.14	9.97	2.69	0.49	1.33	1.55	1.00	0.53	0.04	0.13
	C_2	81.30	10.42	2.36	0.45	1.12	1.72	0.97	0.42	0.07	0.24

CONCLUSIONS

1. The composition of soil parent material has played an important role in determining or modifying certain types of soil profiles developed in Manitoba on sediments of Mankato age.

2. Disintegration of clastic materials has been more active in the soil profiles than in the underlying substrate, but mineral decomposition within the soil profiles has been relatively slight.

3. The rate of weathering of coarse clastic sediments, ranging in size from 2 to 50 millimeters, indicated the following sequence: shale > limestone > other rock fragments.

4. Montmorillonite and illite were the dominant clay minerals found in all the representative genetic soil types in both the grassland and forest regions except in the case of the Brown Podzolic and Podzol types. In the Brown Podzolic soil, iron oxides were found to be important clay components, and feldspars were in greater proportion in the clay of the Podzol soil than in other types.

5. Most of the montmorillonoid and illite minerals were assumed to be pre-Mankato weathering products because of their relatively uniform distribution throughout the profiles. Small amounts of kaolinite also were found commonly in all horizons of the various profiles, which indicated that this mineral was not formed in situ by recent soil-forming processes.

6. The percentage of inorganic carbonates in the soil parent material was one of the important factors that influenced the development of specific morphological characteristics peculiar to certain great soils groups—parent material can determine or cause differentiation in Grey Wooded and Podzol or Brown Podzolic soils; and it can differentiate between the formation of Blackearth and Rendzina types.

7. Abnormally shallow soil profiles resulted when they were developed on excessively high-lime parent materials.

8. In the forested zone, medium textured soils, developed from calcareous sediments, had an accumulation of clay in their "B" horizons, whereas those developed from highly silicic non-calcareous materials studied had little or no clay concentration in any part of the profiles.

9. The lime content of parent material can be a prime factor in determining the extent to which mobile organic colloids are precipitated and retained in the "B" horizon, or removed by downward passage through the profile.

10. The pH or soil reaction is usually considered to be a reflection of the degree of base saturation of the soil adsorption complex. However, it also may be a reflection of the composition of the materials from which the soil is derived.

11. Soils that have high-base status, as the result of the composition of the parent material, may be a more favourable media for organisms and organic decomposition than soils developed in parent materials low in bases.

12. The Brown Podzolic and Podzol soils examined were considered to be young soils in a primary stage of weathering. The relationship of these to their counterparts in more humid, warmer, and older regions appeared to be more morphological than chemical.

13. The data indicate that the only difference between the Grey Wooded, Brown Podzolic and Podzol soils is parent material and it is here inferred that the term "zonal soil" can be a misnomer.

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FACTORS AFFECTING EFFICIENCY OF HONEY BEES (HYMENOPTERA: APIDAE) AS POLLINATORS OF ALFALFA IN SOUTHERN ALBERTA[1]

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ABSTRACT

In studies on pollination of alfalfa by honey bees near Lethbridge, Alberta, in 1951 and 1952, honey bees preferred many other entomophilous plants to alfalfa as sources of pollen. Although the experimental field was isolated from competing crops and competing growth was appreciably reduced both years, the honey bees did not gather pollen from alfalfa until the preferred sources had ceased to flower; then it was so late in the season that few of the tripped flowers had time to produce mature seed. Moreover, honey bees that were caged in alfalfa plots for 33 days did not gather pollen from alfalfa when released. Although accidental tripping of alfalfa by nectar-collecting honey bees is a major factor in the commercial production of seed in Utah and California, it is a minor one in southern Alberta because (*a*) the percentage of flowers tripped is lower than at more southern latitudes, probably because temperature and humidity conditions are not so conducive to automatic tripping; (*b*) fewer honey bees utilize alfalfa as a source of nectar because sweet clover is prevalent in this region; (*c*) there is less time for pollination of flowers and maturation of seed, and (*d*) much of the tripping does not result in cross-pollination, and, hence, fewer pods are formed per flower tripped and fewer seeds per pod. Conclusions drawn from data on seed yields will be erroneous if small populations of efficient native-bee pollinators are ignored where pollination activity of honey bees is low.

INTRODUCTION

Alfalfa flowers must be tripped and cross-pollinated before a seed crop of commercial importance can be produced. The act of tripping aids fertilization by rupturing the stigmatic membrane and providing a liquid medium for germination of the pollen grains and apertures for entry of the pollen tubes (1). The flowers must be cross-pollinated to avoid the collapse of fertile ovules and partial self-incompatibility (4). Dwyer and Allman (5) and Hadfield and Calder (7) found pollen adhering to the standards of untripped flowers and suggested that dissemination of wind- and insect-borne pollen, from flowers that tripped automatically or that were tripped by bees, to the standards of untripped flowers might be a factor aiding cross-pollination; but Lesiņš (13) found that pollen deposited on standards of untripped flowers did not increase seed yield significantly. Pollen deposited in this way would have to be concentrated on the small portion of the standard that is struck by the stigma when the flower is tripped (1).

Although honey bees had not been listed as important pollinators of alfalfa in southern Alberta (6, 9, 10, 18, 19), reports on their successful use in Utah (3, 8, 22) and California (12, 16, 21) in more intensive studies than

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had been done previously in either Canada or the United States prompted the following investigations as to why honey bees are, or are not, of value as pollinators of alfalfa in southern Alberta.

MATERIALS AND METHODS

An isolated 3-acre field was selected for the study in a river valley near Lethbridge, Alberta (Figure 1); at longitude W 112° 59′, latitude N 49° 43′, and an altitude of 2800 feet. The country within 5 miles is range land, or wheat land where strip-farming is practised. The only cultivated plant within this radius that might have competed with alfalfa for the services of honey bees was commercial mustard, which was growing about three miles away. Other competing plants were native species growing on the range, those growing as weeds along roadsides or where land is strip-farmed, or sweet clover, which flourishes in those areas of the river valley that are inundated for short periods during spring floods.

Before and during the experiments, sweet clover (*Melilotus officinalis* (L.) Lam. and *M. alba* Desr.) was sprayed with 2,4-D. Although much of the clover was destroyed, some remained to flower and attract honey bees.

Bumble bee queens were captured when they emerged from hibernation and began to forage on early-flowering plants. Their harmful inquilines, *Psithyrus* spp., were left to prey on those that had managed to escape capture and establish nests. As most of the species of *Megachile* found in the river valley did not emerge until the alfalfa came into bloom, the females were captured when they visited the experimental field in search of food. In 1951, 1871 bumble bee queens were captured before the alfalfa began to bloom; 7 bumble bee workers and 27 female leaf-cutter bees were captured while tripping alfalfa flowers on the experimental field, all after August 14. Only 67 bumble bee queens were taken in 1952; 11 bumble bee workers and 58 female leaf-cutter bees were captured on the field before August 1 of that season. The reduction program was more successful in 1951 than in 1952, as the few native bees captured on the field were taken late in the season. In 1952, more bumble bees and twice as many leaf-cutter bees were removed from the field, and all were captured during the early part of the season, when there was more likelihood that the flowers they tripped and cross-pollinated would have time to set mature seed. The destruction of competing growth may have caused the increase in numbers of native bees on the experimental field in 1952; for example, *Megachile parallela* Sm. was taken on alfalfa for the first time (11).

During the late bud stage of development, the alfalfa was sprayed with a water emulsion of toxaphene or DDT to kill *Lygus* spp. and other pests. In both years, post-spray observations of the amount of bud-blasting and counts of bug nymphs and adults indicated that pest numbers had been reduced to a level such that destruction of buds, flowers, or immature seed was negligible.

Four randomized blocks each of three treatments were set up in the experimental field. The blocks were selected on the basis of uniformity of stand. The plots contained four 20-foot rows, which were 35 inches apart.

The three treatments—bee-excluding, bee-including, and open (free bees)—were designed to give yield attributable to the plant, optimum yield, and yield attributable to the honey bee respectively. Each bee-excluding plot was covered with a cage. When it was judged that there was sufficient bloom to attract honey bees, a 10-frame hive was placed under a cage on each bee-including plot; and during an evening similar hives were placed to the leeward of the alfalfa, 15 hives in 1951 and two rows of 15 each in 1952, for the open plots. A cage (Figure 2) was 6 feet high, and long and wide enough to cover a plot. It was made of 12-mesh amber plastic screen with 6-foot zippers in each corner to allow access from all sides and to allow it to be folded, without creasing, for storage as was that of Pederson, Todd, and Lieberman (15). A foot-wide canvas apron was sewn to the base of each wall. Grommets were fitted in the out-seams joining walls and roof. Spikes on 6-foot poles were inserted through these grommets so as to support the walls and to anchor the guy-ropes that held the cage firmly in place and prevented it from collapsing inwards. The base of each pole rested on the canvas apron, which was draped over 2 in. × 4 in. planks; the apron was nailed to the planks with thin strips of wood.

Pollen was collected from honey bees by trapping to determine preferred sources and to indicate other nectar sources. In 1951 one of the traps used by Vansell and Todd (22) was placed under one of the 15 hives, and dawn-to-dusk samples were taken at approximately 5-day intervals from July 16 to August 18. In 1952, similar traps were placed under the 4 corner hives; samples were taken from July 3 to August 1. Pollen was identified by macro- and micro-methods. The colour of pellets taken from the corbiculae of honey bees captured while collecting pollen from known sources was compared with that of pellets taken from the trap or traps. The colour designation was determined by comparing pellets with the colours in Ridgway's (17) charts. Slides were made of pollen from pellets exhibiting different shades within the same colour range as a check on the accuracy of the initial macro-analysis. These were made by mixing the pollen in a drop of Euparal*. The length and width of 10 normal grains chosen at random were measured, and the mean and fiducial limits at the 5 per cent level calculated when size was the main criterion for species differentiation.

To determine whether honey bees that had been forced to gather alfalfa pollen would continue to do so when released, those on bee-including plots were set free after they had tripped all of the blossoms and their activities were checked during their first days of freedom. In 1951, bees returning with loads of pollen were captured while entering the hives; in 1952, a trap was placed under a hive beneath a cage the night before the bees were released.

To determine the percentage of tripping accomplished by nectar-collecting honey bees, individual bees were closely observed on 10 days from 1950 to 1952 until 1,000 or more visits had been recorded each day. Numbers of honey bees, visits per bee, numbers of flowers tripped, and modes of tripping were noted. Each bee under observation was followed until it was lost from sight, or until it left the field to fly back to the hive.

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FIGURE 1. Setting of experimental alfalfa seed field (*centre, middle distance*) in river valley near Lethbridge, Alberta

FIGURE 2. First replicate of randomized block showing bee-including (*right foreground*), open, and bee-excluding plots.

Counts were made of the freshly tripped flowers (11) on 100 racemes, and of the bees per 100 yards of row to correlate the amount of tripping taking place with free honey bee activity in 1951. The sampler selected racemes far enough ahead of him that he could not distinguish tripped from untripped flowers, and counted honey bees per yard of row every 5 paces along a row, the rows having been chosen at random. In 1951 and 1952, counts were made of honey bees on the two inner rows of each open (free bees) plot and of the number of freshly tripped flowers on 50 racemes on each of the open and bee-excluding plots, so that the amount of automatic tripping could be subtracted from the amount recorded for the open plots before the correlations were made.

To obtain some measure of the effects of temperature and humidity on the amount of automatic tripping that might take place in the field, 6 plants chosen at random were subjected at various times to various temperatures and humidities under controlled conditions in the laboratory by (*a*) gradually raising temperatures from 70° F. to 100° F. and allowing humidities to lower as they do outside, and (*b*) by maintaining relative humidities at about 30-40 per cent as temperatures were raised.

Time available for pollination was the period from the date honey bees began to forage on the field until blooming ceased or until the day after which tripped flowers did not have time to produce mature seed; the latter date was calculated in 1952 by cross-pollinating 10 flowers on one raceme on each of 4 plants chosen at random about every 5 days from mid-July until blossoming ceased, and after the first killing frost (28° F. or lower for more than 3 hours) the resultant pods were harvested and examined for immature, shrivelled seed.

To eliminate the error that might be introduced if alfalfa flowers that came in contact with the sides of the cages were included in yield samples, samples 5 yards in length were taken from the central portions of the two inner rows in each plot. A linear yard of row was considered a square yard because the foliage between rows intermingled and rows were 35 inches apart. In 1951, lack of moisture affected one of the bee-excluding plots and, later, a storm collapsed the cage covering a bee-including plot, removing the flowers on one and knocking off some pods from plants in the other. Snedecor's (20) method of successive approximation was used to estimate values for the damaged plots. Plot samples were threshed with a cyclone plot thresher and cleaned with an office Clipper.

To obtain a measure of the amount of seed damaged by frost and of the amount of cross-pollination, 100-pod samples were taken at random from the inner sides of the rows that remained after yield samples had been taken; sample size was limited by the number of pods on plants in bee-excluding plots. Each pod was threshed by hand; seeds were counted and classed as either plump or shrivelled, and analyses of variance of total seeds per pod and relative percentages of shrivelled seeds were calculated, the latter by Bliss' method for transforming percentages (2).

TABLE 1.—PERCENTAGES OF POLLEN COLLECTED FROM DIFFERENT SPECIES OF PLANTS BY ONE HIVE OF HONEY BEES AT EXPERIMENTAL SITE, 1951

Plant(s)	July			August				Mean
	16	18	25	4	10	15	18	
Melilotus alba Desr. *M. officinalis* (L.) Lam.	67	65	78	45	69	98	86	72.5
Petalostemon candidus (Willd.) Michx. *P. purpureus* (Vent.) Rydb.	0	0	0	47	7	1	2	8.1
Brassica juncea (L.) Cosson	4	6	21	0	0	0	0	4.4
Oenothera biennis L. var. *canescens* T. & G. *O. caespitosa* Nutt. *O. Nuttallii* Sweet	1	1	0	3	23	1	12	5.8
Leguminosae (near *Petalostemon* spp.)	23	24	0	0	0	0	0	6.7
Medicago sativa L.	0	0	0	4	1	0	0	0.7
Other Leguminosae	4	4	0	0	0	0	0	1.1
Miscellaneous	1	0	1	1	0	0	1	0.6

TABLE 2.—PERCENTAGES OF POLLEN COLLECTED BY ONE OR MORE OF 4 HIVES OF HONEY BEES AT EXPERIMENTAL SITE, 1952

Plant(s)	July				August	Mean
	3	4	11	25	1	
Melilotus alba Desr. *M. officinalis* (L.) Lam.	94	99	97	99	99	97.6
Brassica juncea (L.) Cosson	6	1	1	0.5	0	1.7
Cirsium arvense (L.) Scop.	0	0	0	0.4	1	0.3
Medicago sativa L.	0	0	0	*	0	*
Not determined	0	0	2	0	0	0.4

* Less than 0.15 per cent of a 36.35 gm. sample.

RESULTS AND DISCUSSION

Pollen Collection by Honey Bees

Sweet clover was the principal pollen source in both years (Tables 1 and 2). Competitors with sweet clover at different times throughout the flowering period of alfalfa in 1951 (Table 1) were a legume the pollen grains of which looked like those of *Petalostemon* spp. but were significantly smaller; mustard, *Brassica juncea* (L.) Cosson; prairie clover, *Petalostemon* spp.; and evening primrose, *Oenothera* spp. In 1952, sweet clover was subject to very little competition by other species (Table 2). Although no free honey bees were seen to gather alfalfa pollen, pellets of pollen, which appeared to be alfalfa pollen, were found in small amounts in the traps on August 4 and 10, 1951 (Table 1); only a trace was found in 1952 (Table 2). All of the flowers had been tripped on bee-including plots 28 and 33 days after hives had been placed beneath them in 1951 and 1952. In 1951, honey bees that were captured or observed on the day of release were all carrying bright, mustard-yellow pellets of evening primrose; at about the same time, honey bees from the hive beside the field were also gathering pollen from evening primrose (Table 1). In 1952, little alfalfa was in bloom on the open field when the bees were released, and the first daily sample from the traps yielded a mixture of sweet clover and species of Compositae pollen, 94 per cent of which was from sweet clover.

The kinds and amounts of pollen found in the traps both years indicate that the free honey bees foraged in the river valley in which the experimental field was situated. Although a continuing program for the suppression of sweet clover had been carried out, enough remained to provide sufficient pollen. Even if sweet clover had been eradicated, a combination of other species of flowers may have met the demands of the bees for pollen, especially in 1951, when excess rainfall produced more native bloom. Although no other species seriously competed with sweet clover in 1952, less alfalfa pollen was collected in the traps than in 1951. Hence, competition was never reduced to the point where the honey bees were compelled to gather pollen from alfalfa.

Pollination of Alfalfa by Nectar-collecting Honey Bees

An average of 154 visits were made per flower tripped (Table 3). This figure is based on the observation of more than 10,000 visits of nectar-collecting honey bees to alfalfa. The mean percentage of tripping was 0.73, with fiducial limits at the 1 per cent level of 0.47 to 1.06. Most of the honey bees accidentally tripped, with their hind legs, flowers below those from which they were gathering nectar, or they tripped the flowers when they began to climb on the keels of ones higher up on the racemes, or when they alighted directly on the keels. Sexual columns of flowers tripped in these ways usually slapped the standards without first coming in contract with the bee, and as it is unlikely that sufficient viable pollen to effect cross-pollination had been deposited on the standards of the untripped flowers (13), flowers tripped in these ways would not be cross-pollinated. In a few instances, honey bees were struck by the sexual columns and occasionally their tongues or heads were temporarily trapped by them. If these bees

TABLE 3.—AMOUNT OF TRIPPING OF ALFALFA FLOWERS BY NECTAR-COLLECTING HONEY BEES

Sampling date	Number of bees observed	Number of visits observed	Number of flowers tripped
Aug. 7, 1950	13	1073	5
Aug. 25, 1950	21	1143	11
Aug. 28, 1950	5	1028	10
July 19, 1951	19	1078	4
Aug. 15, 1951	18	1141	8
Aug. 21, 1951	10	1012	8
July 3, 1952	6	1075	7
July 7, 1952	23	1011	5
July 23, 1952	16	1011	11
July 31, 1952	7	1004	8
Total	138	10576	77

had tripped other flowers in the same manner, it is likely that this mode of tripping would have resulted in cross-pollination.

Laboratory studies on the effect of temperature and humidity on tripping showed that, when temperatures were gradually raised from 70° to 110° F. and relative humidities allowed to lower from 30 to less than 10 per cent, the flowers wilted and did not trip. When relative humidities were maintained at about 30 to 40 per cent, flowers remained turgid and automatic tripping began to take place when the temperature reached 90° F. Temperatures recorded in louvred meteorological boxes seldom reach 90° F. in southern Alberta and temperatures of alfalfa flowers would probably differ but little from temperatures recorded in this manner (14). If flowers become easier to trip as temperatures approach those at which automatic tripping takes places, it is obvious that nectar-collecting honey bees will trip a greater percentage of flowers visited in more southern latitudes.

The following table shows that, in 1951, the number of honey bees on the field and the amount of tripping were low, and that the bee population on the field did not decrease appreciably from the time honey bees were placed beside it until the alfalfa ceased to bloom, as they did in California (16):

	July						August	
Sampling date, 1951	13	14	16	19	25	29	14	17
Honey bees per 100 square yards	17	16	25	37	23	15	52	59
Freshly tripped flowers per 100 racemes	30	11	13	14	6	6	29	17

TABLE 4.—NUMBERS OF HONEY BEES PER 160 FEET OF ROW OF ALFALFA, AND FRESHLY TRIPPED FLOWERS PER 200 RACEMES ON OPEN AND BEE-EXCLUDING PLOTS

Sampling date	Honey bees	Freshly tripped flowers	
		Open plots	Bee-excluding plots
1951			
July 13	—	70	14
July 14	—	30	33
July 19	10	16	2
July 27	—	42	33
Aug. 1	7	11	10
Aug. 15	25	66	21
Aug. 20	22	42	5
1952			
July 2	15	96	12
July 3	26	68	7
July 7	51	68	16
July 9	52	74	16
July 16	51	104	6
July 23	52	138	19
July 28	51	78	6
July 31	29	104	33

The next year the numbers of honey bees on the field and amounts of tripping taking place were consistently higher but still very low (Table 4, 1952 experiment); at no time was an average of more than one honey bee per square yard counted or of one freshly tripped flower per raceme recorded. In 1952, as the task of reducing the native bee population continued, it became increasingly obvious that their pollinating activities would be great enough to affect results. A highly significant correlation coefficient of + 0.6344 was obtained in 1951 as compared to 0.0070 for 1952 (Table 4), indicating that in 1952 the native bees had not been suppressed as in 1951, and therefore part of the yield could not be attributed to honey bees in 1952.

Factors Influencing Production of Plump Seed

In 1951, sufficient bloom to warrant the placing of hives beside the field was evident by July 12 and the alfalfa remained in bloom until August 25. Killing frost occurred on September 24 and the seed was harvested several days later. In 1952, sufficient bloom was evident by July 1 and the field continued to flower until August 5. The crop was harvested on September 25, 51 days after the field had ceased to bloom and 11 days before the first killing frost. Hence, the total time for pollination and seed setting was 12 days longer in 1952 than in 1951. Seed from flowers tripped after August 15, 1952, was destroyed by frost before it had time to mature. As most of the bloom had died by August 5, little of the shrivelled seed produced that year could be attributed to frost. Hence; the time available for pollination was 35 days. The date after which flowers tripped would

not have time to set mature seed for 1951 is not known. It is probable that the 13 days of cold, rainy weather encountered in late August and early September of that year increased considerably the time required for maturation of seed and, therefore, shortened the time available for pollination.

The mean percentages of shrivelled seeds and mean total numbers of seeds per 100 pods were:

	Shrivelled			Total	
	1951	1952	L.S.D. 0.01	1951	1952
Bee-excluding plots	34.2	29.8	27.5	272	340
Bee-including plots	40.1	10.2	26.1	547	591
Open (free bees) plots	56.1	15.6	11.7	483	484
L.S.D. 0.05	8.5	6.98	—	65.2	47.4
L.S.D. 0.01	—	10.6	—	98.7	71.8

A measure of the loss of seed as a result of frost is seen in the data on shrivelled seeds for 1951; where yields were largely the result of bee visitations (bee-including and open plots), the percentages of shrivelled seed was highly significantly greater in 1951 than in 1952, indicating that much of the seed set by the bees in 1951 did not have time to mature. The percentage of shrivelled seeds per pod was significantly greater on open than on bee-excluding or bee-including plots in 1951; this indicated that seed yields from open plots would not indicate the amount of tripping that had taken place, because more immature seed was destroyed by frost where honey bees were free to gather nectar or pollen than where they were compelled to visit alfalfa and tripped all of the flowers before August 9, or where they were excluded. Although bloom remained on bee-excluding as long as on open plots, most of the flowers that formed pods on bee-excluding plots did so when summer temperatures were more conducive to automatic tripping and hence the seeds were mature when frost occurred. In 1952, the percentage of shrivelled seeds was highly significantly greater on bee-excluding than on bee-including plots, and significantly greater on bee-excluding than on open plots. As flowering had ceased before the date after which freshly tripped flowers would not have time to set mature seed, the greater percentage of shrivelled seeds per pod on bee-excluding plots probably indicated that ovule abortion (a result of selfing) was the main contributing factor. The relatively high percentage on bee-excluding plots in 1951 was probably also the result of selfing.

The number of seeds per pod was highly significantly greater on bee-including and open plots than on bee-excluding plots for both years, indicating that cross-pollination had taken place on bee-including and open plots. In 1952, there were highly significantly greater numbers of seeds

per 100 pods on bee-including than on open plots, indicating that pollination on open plots was a mixture of crossing and selfing. An explanation as to why no significance was found between the bee-including and open treatments in 1951 may be that the activities of the few late-flying, cross-pollinating species of *Megachile* and of pollen-collecting honey bees resulted in enough cross-pollinating to mask the small amount of pollination accomplished by nectar-collecting honey bees.

Mean yields in grams of plump seed per 10 square yards were:

	1951	1952
	gm.	gm.
Bee-excluding plots	2.30	22.03
Bee-including plots	25.03	201.68
Open (free bees) plots	10.45	92.48

Average yields per acre on open plots were 11 lb. in 1951 and 99 lb. in 1952. Theoretically, the amount of seed produced on bee-including plots minus that on bee-excluding plots is the maximum amount that could be produced by honey bees under the particular set of conditions encountered during that growing season. However, the honey bees under cages spent most of their first two weeks of confinement trying to escape or gathering nectar. Hence, a great many blossoms that were open at the time the bees were placed under the cages or that opened during the first week of confinement probably died of old age, and most of the seed was produced from bloom that opened on or after July 20, 1951, and July 10, 1952. Although yields on bee-including plots were highly significantly greater than on open or bee-excluding plots both years, they would have been much higher had the bees begun to gather pollen from alfalfa when they were first placed there.

CONCLUSIONS

As amounts of competing growth in the irrigated areas of southern Alberta where alfalfa is grown for seed closely approximate those in the experimental area, it is unlikely that honey bees will be compelled to gather pollen from alfalfa there. Even if sweet clover were eliminated in and around the seed growing areas, crops like alsike or red clover, or weeds like Canada thistle, *Cirsium arvense* (L.) Scop., or tumbling mustard, *Sisymbrium altissimum* L., would provide preferred pollen sources. Evidently, honey bees cannot be conditioned to gather pollen from alfalfa even by compelling them to gather it for a period of 33 days.

Because nectar-collecting honey bees trip so few flowers and cross-pollinate only a portion of these, and because the pollinating period is so short, they would not set a seed crop of commercial importance. However, as there is no evidence that their nectar-gathering activities make a field less attractive to pollen-gathering native bees, honey bees will be of some importance as long as there are insufficient numbers of native bees to cross-pollinate all of the bloom on a field.

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EFFECTS OF REPEATED APPLICATIONS OF PESTICIDES TO SOIL[1]

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ABSTRACT

The effects of repeated applications of various pesticides to the soil were investigated during 1949 to 1953 in a field experiment at Kentville, N.S. Applications of arsenic, DDT, ferbam, and sulphur caused a decrease in the yields of some crops. DDT, arsenic, and BHC accumulated in the soil, whereas parathion and sulphur did not. There was evidence of translocation of parathion and BHC in plants. Arsenic, sulphur, ferbam, and BHC influenced the chemical composition of the soil.

INTRODUCTION

The introduction of various types of organic compounds has greatly increased the number and variety of pesticides in general use. Many of the newer materials, as well as others that have been in use for a considerable time, are highly toxic. This and the possibility of accumulations resulting from repeated yearly applications make it essential to have information on the effects of pesticide residues in soils.

In the spring of 1949, a field experiment involving pesticides commonly used in orchard sprays was initiated at Kentville, N.S. The results obtained during a 5-year period are presented in this paper.

MATERIALS AND METHODS

The experimental layout was a randomized block design with four replications. The individual plots were 13 ft. × 16 ft. (approximately 1/200 acre) and were separated by 5-foot cultivated strips. The soil in the experimental area has been classified as Berwick sandy loam (9), which is one of the common soil types in the Annapolis Valley.

The pesticides were applied annually in late May or early June before planting. They were added to the surface of the plots in water suspension and then thoroughly incorporated into the soil to a depth of approximately 6 inches with a rotary cultivator. Treatments, together with the rates and years of application, are given in Table 1.

It was estimated that the amounts of pesticides applied annually were roughly comparable to those that would be used in an average spray program during a 5-year period, and thus information in regard to the possible effects of long-term spray programs would be obtained in a relatively short time. Taking an acre of soil to a depth of 6 inches as weighing 2,000,000 lb., the concentration of active ingredient resulting from each application would be: arsenic (As), 45 p.p.m.; DDT, 52.3 p.p.m.; parathion, 15.7 p.p.m.; sulphur (S), 628 p.p.m.; ferbam, 73.2 p.p.m.; BHC 13 p.p.m.; and chlordane, 5 p.p.m.

[1] Contribution No. 282, Chemistry Division, and No. 3318, Entomology Division, Science Service, Canada Department of Agriculture, Ottawa.

TABLE 1.—SOIL TREATMENTS

Pesticide	Annual application (lb./ac.)	Years of application
Lead arsenate ($PbHAsO_4$)	419	1949, 1950, 1951, 1952, 1953
DDT (50% W.P.)	209	1949, 1950, 1951, 1952, 1953
Parathion (15% W.P.)	209	1949, 1950, 1951, 1952, 1953
Sulphur (S)	1,256	1949, 1950 — — –
Ferbam (70% active ingredient)	209	1949, 1950, 1951, 1952, 1953
BHC (50% W.P. 6% gamma)	52	— 1950, 1951, 1952, 1953
Chlordane (40% W.P.)	25	— — 1951, 1952, 1953

Beans, buckwheat, carrots, and potatoes were used as test crops from 1949 to 1953, inclusive. Onions were included in 1951 and 1952. Either 3-15-6 or a 6-12-6 fertilizer at 800 or 1,000 lb. per acre was applied annually and manure was also used in 1949 and 1951. The crops were grown in the same relative position each year but were rotated annually within each plot so that the same crop was not grown in the same row in successive years. At maturity the crops were harvested, yields recorded, and representative samples taken for the determination of pesticide content.

Composite soil samples, representative of the 0-6 inch depth, were taken from each plot before and immediately after each annual pesticide application and again at the end of the growing season. Determinations for nitrate nitrogen were made according to the A.O.A.C. method (11) and organic matter, exchangeable bases (calcium, magnesium, potassium), total and available phosphorus, exchangeable manganese, and pH values were determined by methods given by Wright *et al.* (14).

The following methods were utilized in determining the pesticide content of soil and plant samples: arsenic, Allcroft and Green (2) and A.O.A.C. (11); DDT, Donovan (7) and Schechter *et al.* (13); parathion, Averell and Norris (4); BHC, Donovan (7) and Schechter and Hornstein (12); chlordane, Davidow (6); sulphur, soil samples extracted with carbon tetrachloride, plant samples wet ashed with nitric and perchloric acids, sulphates precipitated with barium chloride and weighed. A satisfactory chemical method for the determination of ferbam was not available.

Crop yield data as well as the results of chemical analyses were treated statistically by making an analysis of variance, and Student's *t* test was used to determine what treatments were significantly different from the check.

RESULTS AND DISCUSSION

Crop Yields

The average yields are presented in Table 2.

Arsenic, applied to the soil as $PbHAsO_4$, was considered the toxic element in the lead arsenate, although the possibility of lead toxicity is recognized. In plots treated with lead arsenate there was a significant reduction in the yield of beans in 1950 and in each succeeding year up to and including 1953; no consistent effects on the yields of other crops

TABLE 2.—EFFECTS OF PESTICIDES ON CROP YIELDS

(Average yields of four replicates—pounds per plot)

Crop	Year	Pesticides applied							Check
		Arsenic	DDT	Parathion	Sulphur	Ferbam	BHC	Chlordane	
Potatoes (tubers)	1949	44.3	46.1	40.7	37.0	38.1	—	—	38.5
	1950	16.1*	20.0	23.9**	2.8**	16.2*	25.9**	—	19.2
	1951	19.4	21.6	17.1	6.0**	15.4	19.2	22.3	19.1
	1952	15.4	19.4	21.1	0.8**	15.5	20.6	18.5	16.1
	1952	18.6	26.0	29.3*	16.2	23.4	25.5	25.3	20.9
Carrots (roots)	1949	24.4	28.0	25.1	12.4**	23.6	—	—	25.5
	1950	18.7	15.9	11.6	0.0**	13.1	12.8	—	15.4
	1951	25.3	24.4	19.7	2.2**	16.1	15.2	20.3	19.5
	1952	10.0	12.8	10.9	0.0**	7.5	17.2	9.6	13.7
	1953	31.6	42.3	34.3	5.1**	23.5**	38.8	36.6	35.8
Beans (green beans)	1949	3.2	3.1	3.8	2.5**	3.1	—	—	3.4
	1950	3.1**	2.7**	4.2	0.3**	3.4**	4.9	—	4.7
	1951	2.4**	1.9**	5.4	2.2**	3.3**	5.8	5.8	6.1
	1952	2.8**	2.9**	6.4*	1.7**	5.2**	8.0	6.5	7.9
	1953	1.2**	1.1**	5.6	2.2**	3.7	5.4	4.5	4.8
Buckwheat (aerial portion)	1949	19.4	18.4	20.4	7.9**	17.3*	—	—	21.7
	1950	17.8*	12.9	16.4	2.5**	6.1**	14.6	—	12.5
	1951	19.8**	13.2	13.5	11.5	12.1	11.9	15.8	14.8
	1952	22.4	14.4	20.0	16.6	16.8	15.4	18.0	21.7
	1953	16.7	8.7**	12.3	14.9	11.6	10.4*	13.0	15.9
Onions (bulbs)	1951	8.4	5.9*	7.0	0.1**	3.4**	5.7*	6.5	8.3
	1952	4.9	2.2*	3.9	0.2**	1.4**	2.6	3.3	3.6

* Significant at P 0.05.
** Significant at P 0.01.

resulted. Serious accumulations of arsenic have been reported where heavy dosages have been applied for insect control. Foster (8), reviewing the arsenical residue problem in the western United States, reported that arsenic accumulations in the surface soil were largely responsible for increasing difficulties in the growing of certain cover crops although deep-rooted orchard trees remained unharmed. Cooper *et al.* (5) reported a marked reduction in certain crops grown on areas previously sprayed with arsenicals for control of cotton insects.

DDT caused a significant reduction in the yield of beans in the years 1950 to 1953, inclusive, of buckwheat in 1953, and of onions in 1951 and 1952. Several workers have reported reduction of crop yields resulting from heavy applications of DDT to the soil. Lindgren *et al.* (10) have shown that 128 lb. or over of DDT per acre caused reduction of yield of Stringless Black Valentine bush beans. A report by Foster (8) states that 100 lb. per acre caused a reduction in the yield of the same variety of beans. Ackley *et al.* (1) have reported that residues of DDT resulting from treatments for insect control had approached phytotoxic levels when soil samples in 29 orchards of the Wenatchee and Yakima areas showed an accumulation of 22 to 62 lb. of DDT per acre in the surface 4 inches of soil under the spread of the trees.

Parathion-treated plots showed no consistent differences from the checks in crop yields. It appears improbable that phytotoxic accumulations of parathion will result from pest control treatments at recommended dosages. Foster (8) states that toxic residues in the soil are not an object of concern but indicates that a temporary depressing effect on germination and stand may occur.

Sulphur, which was applied only in 1949 and 1950, caused reduction in crops yields of carrots and beans in 1949 to 1953, inclusive, of potatoes in 1950 to 1952, inclusive, of buckwheat in 1949 and 1950, and of onions in 1951 and 1952. There was, therefore, a yield recovery of buckwheat in one year and of potatoes in three years after the last sulphur treatment.

Ferbam reduced the yield of beans in 1950, 1951, and 1952, of potatoes in 1950, of carrots in 1953, of buckwheat in 1949 and 1950, and of onions in 1951 and 1952. The effects of this material, which were seemingly inconsistent, suggest the possibility of indirect or secondary effects on crop growth.

BHC caused a highly significant increase in the potato crop in 1950, the first year this pesticide was applied. A significant decrease in the yield of onions resulted in 1951 but did not recur the following year. The buckwheat crop was decreased in 1953. The rather inconsistent results indicate a secondary or indirect rather than a straight toxic effect on the crops. Foster (8) found that technical BHC at 400 lb. per acre "virtually eliminated all growth" of some 15 crops being tested. The highly purified gamma isomer of BHC, however, is reported by the same workers as having no adverse effects on germination and stand of crops even at concentrations of 400 lb. per acre.

Chlordane treatments applied in 1951, 1952, and 1953 at the rate of 10 lb. actual toxicant per acre did not affect the yield of the test crops. Foster (8) found that chlordane at 25 lb. per acre depressed the stand of most vegetable crops.

Accumulation of Pesticides in the Soil

The concentrations of the active ingredients of the added pesticides at dates of application and at the end of each growing season for the years 1949 to 1953, inclusive, are presented graphically in Figure 1.

Arsenic, *DDT*, *BHC*, and *chlordane* appeared to be relatively stable in the soil. Although there was a gradual decrease in concentration of these compounds in the soil throughout the year, their repeated application resulted in a build-up. Allen *et al.* (3) reported that plots treated with 100 lb. of DDT per acre in 1947 had a residue of 28.2 lb. per acre in 1951 in the top 6 inches of soil, and that after 3 years about one-half of a 100 lb. per acre application of BHC had disappeared.

Parathion disappeared rapidly from the soil. After annual spring applications of 15.7 p.p.m. active ingredient over a period of 5 years, the final concentration in the soil at the end of the fifth year was only 0.5 p.p.m. This finding agrees with the conclusions of Foster (8) on the instability of the compound.

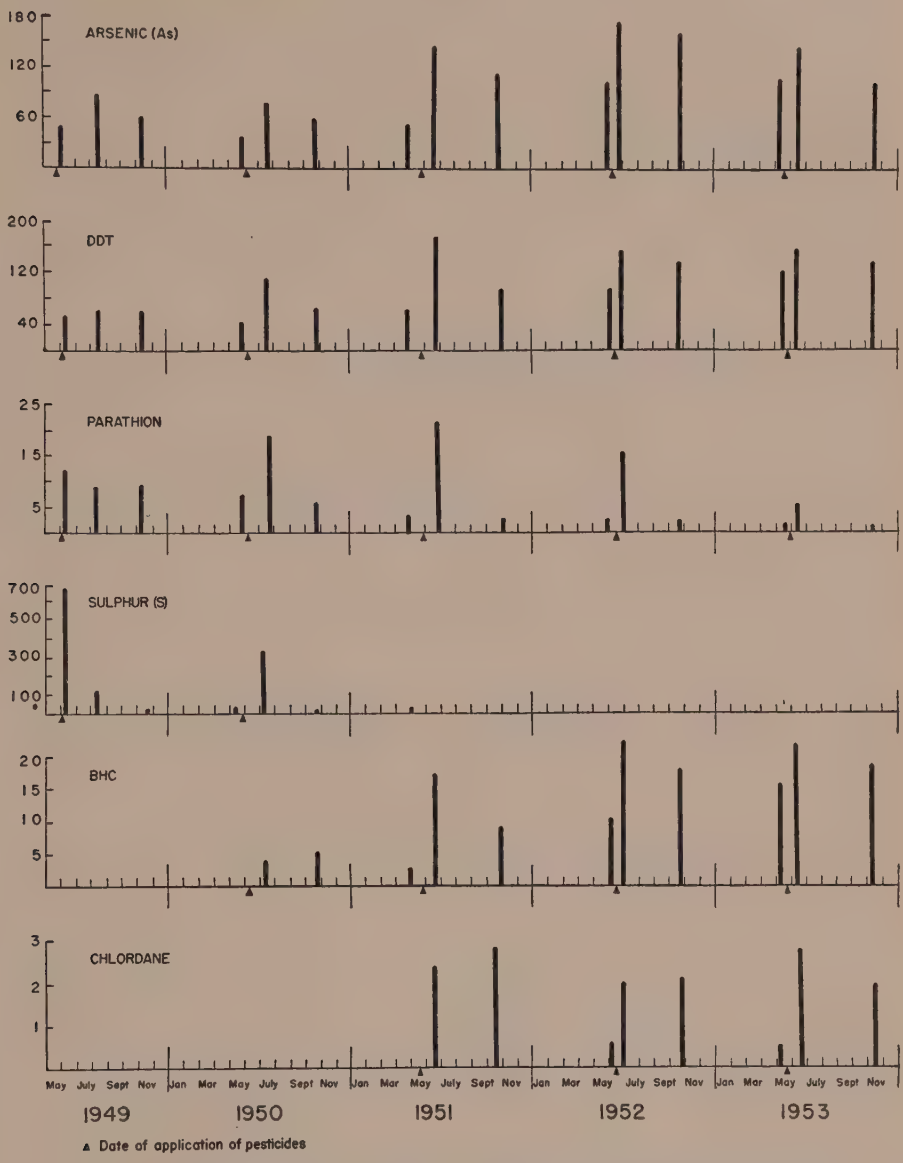

FIGURE 1. Concentration of pesticides in the soil in p.p.m. of active ingredient, air dry basis.

Sulphur applications resulted in marked increases in soil acidity, and elemental sulphur rapidly disappeared.

Translocation of Pesticides to Plants

Chemical analyses were made of the plants grown and the following conclusions arrived at as to translocation.

There was definite evidence of translocation of parathion in beans and buckwheat. Although parathion was not found in the edible part of the bean plant, that is, the pod and contents, it was found in the leaves and stems. It was found also on the surface of carrots and on the peel of potato tubers grown in parathion-treated soil.

There did not appear to be any appreciable degree of translocation of DDT or chlordane in the plants grown in this experiment. Traces were found only on the surface of carrots and potatoes, and were probably due to contamination from the soil.

Translocation of BHC to root crops, that is, potatoes, carrots, and onions, was indicated by organoleptic tests and the presence of BHC was definitely shown by microchemical analytical methods.

Increased concentrations of arsenic in the soil resulted in an increased arsenic content in the plants.

Crops tended to avail themselves of increased sulphur in the soil provided the sulphur concentrations were not such as to prove injurious to crop development.

Effects of Pesticides on the Chemical Composition of Soil

Soil fertility investigations by chemical analytical methods indicated the following:

Arsenic, considered to be the active ingredient in lead arsenate, had no significant effect on pH, readily soluble phosphorus (Truog's method), exchangeable basis, exchangeable manganese, or organic matter. Nitrate nitrogen content was significantly higher in the 5-year averages but not on a yearly basis.

DDT, parathion, and chlordane had no significant effect on the pH of the soil or on the concentrations of the plant nutrients determined.

Sulphur added as elemental sulphur at 1,256 lb. per acre in each of two successive years lowered the pH of the soil from 5.16 in 1949 to 3.70 in 1950. Although sulphur was not added in the last three years of the experiment, in 1953 the pH of the treated plots was still significantly lower than that of the checks. There was, however, a gradual decrease in soil acidity from 1951 to 1953. Nitrate nitrogen content was significantly lowered. The concentrations of the exchangeable bases calcium and magnesium were significantly decreased as a result of the sulphur treatments but the 5-year average for potassium was found to be not significantly different from that for the check plots.

Ferbam significantly decreased the nitrate nitrogen content of the soil in the third, fourth, and fifth years of the experiment and the 5-year average was also significantly reduced. The amount of exchangeable manganese was significantly increased in the third and fifth years as was also the 5-year average.

BHC treatments significantly increased the exchangeable manganese content in each of the four years it was applied.

CONCLUSIONS

The continuous use of arsenic, DDT, ferbam, or sulphur for pest control purposes presents the danger of an eventual build-up in the soil that may be detrimental to plant growth. This is particularly true where comparatively large dosages are applied repeatedly, as in orchards.

The effect of ferbam on the nitrate nitrogen content and that of BHC on exchangeable manganese indicated that these compounds exerted an influence on soil organisms.

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THE INFLUENCE OF FIELD SHELTERBELTS ON WIND VELOCITY, EVAPORATION, SOIL MOISTURE AND CROP YIELD[1]

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ABSTRACT

Five years' measurements of the influence of field shelterbelts on wind velocity, evaporation, soil moisture and crop yield are described. It is shown that shelterbelts and hedge rows reduce the velocity of cross-winds to a distance at least 20 times the height of the trees. In this way hedge rows, once established, reduce the hazard of soil drifting. The reduction in evaporation observed near field shelterbelts was small, and from the information available it does not appear likely that it would have a measurable influence on soil moisture conservation or wheat yield.

Snow accumulation near shelterbelts varied from almost nil in years of low snowfall to drifts 70 feet wide in years of ample snowfall and strong winds. These snow drifts increased the soil moisture near the shelters at seeding time, and this in turn resulted in greater yields than obtained in the centre of the fields. The net increase in yield in one group of sheltered fields for the 5-year period, taking into account the area occupied by the trees, was 0.7 bushel per acre. Increased yields due to snow accumulation in shelterbelt projects may occur to the extent that loss of snow to ditches or gullies is prevented or the distribution of the snow is improved.

During the period 1930-40 farmers in the Canadian Prairies suffered severe crop losses from drought and soil drifting. Many methods of moisture conservation or erosion control were suggested, and, as far as possible, brought into use during that period. One of the methods proposed, chiefly for the control of soil drifting, was the planting of field shelterbelts at intervals of 20 to 50 rods across the fields. To test the feasibility of this proposal, the Federal government in 1935 established shelterbelt projects at Conquest and Aneroid, Saskatchewan and at Lyleton, Manitoba, where soil drifting had been severe. Tree planting, under the direction of the Forest Nursery Station at Indian Head, progressed rapidly until by 1954 the combined area of the projects was over 350 square miles, of which 144 square miles was planted to a complete system of field shelterbelts. The largest project at Conquest had 550 miles of hedges, that at Aneroid had 172 miles, and Lyleton had 315 miles of hedges.

Before these shelterbelts were developed a program was initiated at the Soil Research Laboratory to find the influence of available shelterbelts on wind velocity, soil moisture and crop yield. This work was carried on from 1935 to 1940 when it was discontinued. In the early 1940's the Forest Nursery Station commenced measurements of soil moisture and crop yield in fields adjacent to the earlier plantings at Conquest. This work was continued until 1949 when the project was revised to include measurements at Aneroid and Lyleton as well as at Conquest.

In the revised project, the Forest Nursery Station supervised the planting and maintenance of the shelterbelts and compared the suitability of various plantings for use in the area. The Experimental Farms at Brandon, Manitoba, and Scott, Saskatchewan, measured the influence of

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Soil Research Laboratory at Swift Current obtained crop yields at Aneroid, and measured the effect of shelterbelts on wind velocity, evaporation, snow accumulation and soil moisture at all locations. The present paper deals with the results obtained in the above program by the Soil Research Laboratory during the period 1950-54.

REVIEW OF LITERATURE

The influence of windbreaks on the microclimate and crop growth in protected fields was studied in considerable detail in the United States by Bates (1) prior to 1911. He showed that evaporation was decreased to leeward a distance of at least ten times the height of the trees. Air temperatures measured near the shelterbelts were higher than those measured in the open during the daytime and lower during the night.

A summary of extensive measurements made near wide, dense shelterbelts in Russia was published by Rudolf and Gevorkiantz (6). The shelterbelts reduced evaporation more than they did relative humidity between the strips. In many seasons increases in yield up to 30 per cent were obtained between the shelterbelts, compared with the open steppe. Reduction in wind velocity was reported by these and other authors (2) (3) (9) to extend to leeward a distance of 10 to 30 times the height of the trees, a mean of 20 times the height being commonly accepted.

WIND VELOCITY

Robinson cup-type recording anemometers supplied by the Meteorological Division of the Department of Transport were used to measure the wind velocity between field shelterbelts. These instruments were used for a few weeks each spring, when the strongest winds were usually experienced, and when the growth in the fields was too small to interfere with the measurements. In each test some instruments were placed in exposed positions with no shelterbelts to windward, and others were distributed at various distances to leeward of the hedges or shelterbelts under study. The anemometers were adjusted to a height of 30 inches above ground. Care shelterbelts on crop yields at Lyleton and Conquest respectively. The was taken to see that surface roughness and crop growth were comparable at the exposed and protected sites. The wind velocity and direction were recorded continuously by an anemometer at a height of approximately 40 feet in the Conquest area. Combining the wind speed between shelterbelts with the direction records, it was possible to estimate the influence of shelterbelts on winds from various directions.

Table 1 shows the mean influence of shelterbelts on wind velocity obtained from a large number of measurements. The results are expressed as percentages of the exposed velocity recorded at different distances to leeward. As is customary in this work, the distances are given as a multiple of the tree height. These results, obtained near dense single row hedges and 2- and 3-row shelterbelts with winds blowing almost perpendicularly across the rows, show that some reduction in wind speed occurred beyond 30 times the height of the trees. The influence tapered off gradually so that the exact limit was impossible to determine. It would appear, too,

TABLE 1—WIND VELOCITY TO LEEWARD OF FIELD HEDGES AND SHELTERBELTS

Distance to leeward of shelterbelt	Per cent of the exposed wind velocity	*Example 1:* Single row cara. 7′ tall, distance leeward	*Example 2:* 3-row cara., ash, maple 20′ tall, distance leeward
		ft.	ft.
2.5 x height	40	—	50
5 x "	35	35	100
7.5 x "	48	52	150
10 x "	60	70	200
12.5 x "	68	88	250
15 x "	73	105	300
20 x "	80	140	400
25 x "	84	175	500
30 x "	88	210	600
35 x "	92	245	—
40 x "	95	280	—

that the degree of sheltering varied somewhat with the wind speed and the stability of the atmosphere. The extent of influence obtained in Table 1 was almost identical with that reported by Bates (2).

The wind is not always blowing directly across the hedge rows as envisaged in Table 1, so that the average extent of influence is less than that shown. The commonly accepted distance of sheltering, 20 times the height of the trees, is believed to be a good average for crosswinds making angles up to 45 degrees with tree rows. This factor would apply to strong crosswinds which might cause soil drifting or other damage to the crop during short periods.

Measurements of wind velocity made between successive hedges spaced at 27- or 40-rod intervals showed that no cumulative sheltering resulted with a greater number of hedges to windward. Bates (2) obtained a similar result although some cumulative effect had been reported by Leontievsky (4).

The recording type of anemometer required too much attention for use in obtaining integrated wind milages at various sites throughout the summer. The latter were needed in order to find the mean wind speeds influencing evaporation and transpiration between the shelterbelts. These data were obtained by means of ten dial-type anemometers which indi-

TABLE 2—WIND VELOCITY AT 30 INCHES ABOVE FALLOWED FIELDS AT CONQUEST, JUNE TO SEPT. 1952-54

Year	Exposed	Centre of 40-rod strip, shelterbelts 20-25 ft. high	Centre of 40-rod strip, hedges 7-9 ft. high
	mi./hr.	mi./hr.	mi./hr.
1952	6.38	5.49	6.29
1953	6.60	5.13	6.34
1954	6.19	5.18	5.68
3-year mean	6.39	5.27	6.10
Per cent of exposed	100	82	95

TABLE 3—WIND VELOCITY AT A 40-FOOT HEIGHT, CONQUEST, MAY-SEPT. 1950-54*

Year	Wind direction	May		June		July		August		September		May to September	
		Days	Wind vel.	Days	Wind vel.	Days	Wind vel.	Days	Wind vel.	Days	Wind vel.	Days	Wind vel.
			mi./hr.		mi./hr.		mi./hr.		mi./hr.		mi./hr.		mi./hr.
1950	W	—	—	13	10.9	14	8.3	17	7.9	14	11.5	—	—
	E	—	—	5	9.9	10	6.9	11	6.0	10	7.0	—	—
	Var.	—	—	12	9.4	7	6.7	3	8.3	6	6.3	—	—
	Total	—	—	30	10.2	31	7.5	31	7.3	30	9.0	—	—
1951	W	14	11.9	16	9.6	9	9.3	7	10.1	12	9.5	58	10.1
	E	4	12.0	7	12.4	10	9.1	15	8.5	1	3.1	37	9.6
	Var.	1	10.4	7	8.1	12	7.5	9	7.4	3	7.8	32	7.8
	Total	19	11.9	30	9.9	31	8.6	31	8.6	16	8.8	127	9.4
1952	W	12	8.8	12	11.1	24	9.7	15	8.3	15	10.0	78	9.6
	E	10	7.1	10	11.5	4	7.1	2	7.6	5	8.2	31	8.8
	Var.	7	7.9	8	10.0	3	5.9	14	7.4	10	7.9	42	8.0
	Total	29	8.0	30	11.0	31	9.0	31	7.8	30	9.0	151	9.0
1953	W	9	9.4	14	10.1	14	8.5	8	10.4	11	10.0	56	9.6
	E	10	10.3	7	9.8	4	10.5	3	5.7	2	7.6	26	9.4
	Var.	12	9.1	9	8.4	13	8.2	20	6.3	17	7.7	71	7.7
	Total	31	9.6	30	9.5	31	8.6	31	7.3	30	8.5	153	8.7
1954	W	10	11.5	20	9.6	20	9.6	10	7.9	9	8.3	69	9.4
	E	11	11.4	4	11.0	3	7.6	12	7.8	7	10.6	37	9.7
	Var.	10	7.5	6	6.5	8	8.0	9	9.4	14	7.6	47	7.8
	Total	31	10.2	30	9.2	31	9.0	31	8.3	30	8.5	153	9.0

* Records obtained by H. M. Kennedy, Conquest.

TABLE 4—PRECIPITATION AND FREE-WATER EVAPORATION AT SHELTERED AND EXPOSED SITES, CONQUEST, 1950-54

Period	Year	40-rod strip, N-S, 3-row shelterbelt 20-25′ tall				Site 1 (exposed)		Site 2 (exposed)	
		Precip.	Evaporation			Precip.	Evap.	Precip.	Evap.
			East*	Centre	West*				
		in.	in.	in.	in.	in.	in.	in.	in.
May to Sept.	1950	8.1	28.3	28.3	28.4	9.3	26.5	—	—
June to Aug.	1951	9.3	13.8	14.4	13.5	8.6	16.2	9.3	14.8
May to Sept.	1952	9.4	23.8	25.2	23.6	7.5	26.4	9.3	29.3
May to Sept.	1953	10.1	23.9	26.4	24.0	10.3	26.7	10.4	26.4
May to Sept.	1954	11.8	18.5	19.4	17.1	11.8	21.0	11.6	18.6
Total		48.7	108.3	113.7	106.6	47.5	116.8	40.6	89.1
Mean		9.7	21.7	22.7	21.3	9.5	23.4	9.9**	23.4**

*10 rods from shelterbelt in 1950
5 rods from shelterbelt in 1951-54
**Weighted mean
(Fields cropped to wheat 1950-53, fallow 1954)

cated total milage only. The instruments were placed at a height of 30 inches over summerfallow during the summer months and were read at 2-week intervals. Results obtained from these instruments, given in Table 2, show that the mean wind speed in the centre of a 40-rod strip protected by a tall 20-foot shelterbelt was reduced to 82 per cent of the wind in the open, and that the wind speed in a similar field protected by a 7-foot hedge was reduced to 95 per cent. Although the latter reduction may be real, it is very small, and the difference of 5 per cent is within the possible error of the instruments. In 1953 anemometers placed at 10 rods from 7-foot caragana hedges on each side of a 40-rod fallowed strip showed 7 per cent reduction compared with the instruments in exposed positions. In 1954 the anemometers, moved to 5 rods from each hedge, showed a reduction of 19 per cent compared with the exposed instruments and 12 per cent compared with that at the centre of the field. The combined results showed that the mean wind milage was reduced by over 15 per cent at all points within a 40-rod strip protected by a tall 20-foot shelterbelt, but that comparable protection was afforded only in 5- and 10-rod strips near 7-foot hedges.

Table 3 shows the wind velocities recorded at a height of approximately 40 feet at Conquest for the months May to September 1950-54. Since most of the field shelterbelts were in rows running N—S, the wind directions were listed as westerly, easterly and variable. The latter included winds that were not predominantly from the west or east, such as directly north or south, and winds that changed through many quarters during the day. The mean values in the table show that west winds occurred on almost twice as many days as east winds, and that in most cases their number also exceeded the variable winds. The velocities of the westerly winds were greater than those from the east and much greater than those from variable directions.

SOIL DRIFTING

Soil drifting has not occurred very frequently during the past five seasons partly because of the favourable moisture conditions. Only a few actual comparisons have been made of soil drifting tendencies inside and outside the shelterbelt projects. On May 25 and 26, 1951, soil drifting was prevalent to the north, east and west of the Conquest project whereas only a slight sifting was noted in two places in fields between the hedge rows. Similar observations were made at Lyleton* in the early summer and late autumn of 1952. As far as is known, no severe soil drifting has occurred within any of the shelterbelt projects since they were established. The soil drifting hazard must decrease in proportion to the reduction in wind velocity to leeward of the hedge rows.

It is true, of course, that a loose, dry soil as well as a high wind speed is necessary to produce soil drifting. The soil condition depends on a great many factors such as soil texture, type of cultivation, soil moisture content, stubble mulch, and so on. It is possible that some of the soils outside the shelterbelt area were in a more susceptible condition than those near Conquest. However, the farms within the shelterbelt project include a range

* Reported by D. A. Duncan, Agronomist, Experimental Farm, Brandon, Man.

of soil types, some of which are highly erosive, and many different farming practices are followed. It seems probable that some of the farms within the area would have eroded badly without shelterbelt protection, and, similarly, many of the fields outside the area might not have drifted had protection been provided. Planting rows of trees at 20- to 40-rod interval divides the land in a manner comparable to strip farming, and this alone provides some insurance against erosion. If, in addition, the hedge or shelterbelt reduces the wind speed appreciably over one-third to one-half the width of the strip, the likelihood of soil drifting is correspondingly reduced.

EVAPORATION

Four free-water evaporation tanks of the type used by the Meteorological Division were installed at the Conquest project by the staff of the Forest Nursery Station in 1949. Three tanks were placed at distances of 10-, 20- and 30-rods, respectively, from the west side of a 40-rod field of wheat running N—S. The field was protected on the west and east sides by 3-row shelterbelts of caragana, ash and maple of heights at that time of about 18 feet. The fourth tank was installed in an exposed wheat field about 7 miles to the northeast. A fenced enclosure, approximately 20 feet square, was placed around the tanks to keep animals out, and weed or crop growth was kept down inside the fence. Rainfall records were obtained at both sheltered and exposed sites. The results in 1950 showed little difference in evaporation between the three tanks in the sheltered field, so that in 1951 the outer tanks were moved to within 5 rods of the shelterbelts. In 1951, too, another exposed tank was installed in a wheat field 7 miles southwest of the sheltered field. The tanks were used in cropped fields until 1954 when all were in summerfallow.

TABLE 5—THE EFFECT OF WIND DIRECTION ON EVAPORATION

Year	Wind direction	Number of days	Evaporation			Wind velocity
			East	Centre	West	
			in.	in.	in.	mi./hr.
1951	W	58	10.87	10.79	9.45	10.1
May 13 to Sept. 16	E	37	4.90	5.48	5.61	9.6
	Var.	32	4.12	4.04	3.96	7.8
	Total	127	19.89	20.31	19.02	9.4
1952	W	78	13.48	13.54	12.18	9.6
May 3 to Sept. 30	E	31	3.95	4.86	5.12	8.8
	Var.	42	6.37	6.84	6.30	8.0
	Total	151	23.80	25.24	23.60	9.0

The evaporation records are given in Table 4. The mean values in the last row show that differences in evaporation were small between different points in the sheltered field and also between the sheltered and exposed sites. The mean evaporation losses in the centre and on the east and west sides of the sheltered field for the 5-year period were 3, 7 and 9 per cent respectively less than that in the exposed fields. If only the last 4 years were considered, when the tanks were 5 rods from the shelterbelts, the reduced evaporation losses at centre, east and west were 5, 11 and 13 per cent respectively less than the exposed. In noting that the reduction in evaporation is rather small for shelterbelts that are now 25 feet in height, it should be remembered that the recent seasons have been relatively humid without strong winds. On the other hand, this work would indicate that the reduction in evaporation near the shorter caragana hedges, which are the common type in the projects, must be very small.

The effect of wind direction on evaporation across the sheltered strip is shown in Table 5 for May to September 1951 and 1952. When winds were in the west or east the tank on one side or other of the field was sheltered and the evaporation correspondingly reduced. The evaporation on the sheltered side was reduced 10 to 20 per cent compared with that on the opposite side of the field.

The results show that the percentage reduction in evaporation is consistently less than the corresponding reduction in wind velocity. The meteorological factors most likely to influence evaporation are temperature and relative humidity of the air, and wind velocity. Temperature and relative humidity have not been recorded at the Conquest project, but during a short period in June 1951 no definite differences in these factors could be established with a sling psychrometer at different locations in the shelterbelt area. Other workers have reported only minor influences of shelterbelts on the humidity of the air (1) (6). Wind velocity is believed to be the main factor influencing the free-water evaporation. Penman's (5) form of the equation for evaporation from a free-water surface is:

$$E = 0.35\ (e_o - e_d)\ (1 + 9.8 \times 10^{-3} u_2)$$

where e_o is the vapour pressure at the surface of the water, e_d is the vapour pressure of the air and u_2 is the wind speed in miles per day at a height of 2 meters. This shows that the evaporation varies approximately as $(1 + 0.01\ u_2)$ so that with an average u_2 of 170 miles per day the percentage change in evaporation will be less than the corresponding change in wind speed.

Experiments carried out at the Soil Research Laboratory have shown that neither evaporation from soil (7) nor evapotranspiration from crops (8) is directly proportional to the free-water evaporation when moisture supplies are limited. Meteorological conditions are the sole controlling factors only when the soil surface is moist or the crop is amply supplied with moisture; otherwise soil moisture content and the movement of moisture to the evaporating surfaces limit the evaporation rate. It seems unlikely that reduced wind speeds, causing differences in free-water evaporation of the order observed between the field shelterbelts, would have appre-

ciable influence on evaporation from soil, or evapotranspiration from crops, under the moisture conditions normally experienced in the area.

SNOW ACCUMULATION

Measurements of snow accumulation near field shelterbelts at Conquest, Aneroid and Lyleton are presented in Table 6. The data in column 3 show that the mean widths of drifts on the east and west sides of the shelters were 30 to 70 feet for the first three years of the project but were only 12 to 40 feet in the last two years. Frequently the widths on the east side of the hedges were greater than those on the west, and therefore greater than the mean values shown. The data apply to the main portion of the drifts; usually some additional snow tapered off toward the centre of the fields.

The hedges hold all the snow that falls within the project area, and there is no evidence of snow drifting into the fields from outside. It is difficult to say whether or not the snow depths in the centre of the sheltered fields are identical with those in similar exposed fields. In stubble fields the height of the stubble is the main factor determining snow depth. One would expect a net gain from snow in a shelterbelt project compared with exposed fields only to the extent that loss was prevented along roadsides

TABLE 6—SNOW ACCUMULATION NEAR FIELD SHELTERS AT CONQUEST, ANEROID AND LYLETON, 1950-54

Station	Year	Width of drift	Average depth	Maximum depth	Depth at centre of field		Recorded snowfall Nov.-Mar.
					Stubble	Summer-fallow	
		ft.	in.	in.	in.	in.	in.
Conquest	March 17, 1949-50	29	26	36	3	1	24
	March 20, 1950-51	64	45	65	10	6	35
	March 29, 1951-52	35	25	37	12	4	33
	March 18, 1952-53	30	14	18	6	3	26
	March 24, 1953-54	12	6	12	0	0	20
	Mean	34	23	34	6	3	28
Aneroid	April 11, 1950-51	45	16	22	0	0	—
	March 29, 1951-52	30	41	46	12	8	—
	March 14, 1952-53	15	16	19	8	4	—
	March 23, 1953-54	13	20	24	8	5	—
	Mean	26	23	28	7	4	—
Lyleton	March 15, 1949-50	58	23	42	6	0	57
	April 3, 1950-51	69	18	24	4	—	60
	April 1, 1951-52	34	12	15	8	—	32
	March 20, 1952-53	40	11	22	4	4	28
	March 25, 1953-54	15	24	24	0	0	42
	Mean	43	18	25	4	—	44

and gullies, or that the distribution was improved, i.e., more snow was held on knolls and less in low places.

The specific gravity of snow in March is usually about 0.33 or 3 inches of snow to 1 inch of water. The penetration of moisture from snow in stubble fields is often good, although some run-off may occur following rapid spring thaws. A small amount of moisture is conserved from snow on exposed fallow fields in about five years out of ten. Most loam soils will hold only 6.5 inches of water in the 4-foot root zone so that, assuming no loss, 20 inches of dense snow would be all that was needed. Some miosture is lost below the root zone near shelterbelts in years of high snowfall or when the combination of short stubble and strong winds has resulted in deep snow drifts.

SOIL MOISTURE AND CROP YIELD

The effects of field shelterbelts on soil moisture and wheat yield will be considered together because the same fields were sampled for both. Beginning in 1950, four fields were sampled each year at Conquest and Aneroid and two fields at Lyleton. Two of the fields at Conquest were between 3-row shelterbelts of caragana, ash and maple, 20 to 25 feet in height, and the other two were between the common single-row caragana hedges 7 to 9 feet in height. The hedges at Aneroid were all single rows of caragana. The soil moisture data obtained at Conquest and Aneroid, and the crop yields obtained at Aneroid, are presented here. The soil moisture sampling was not satisfactory at Lyleton as the soils were frequently waterlogged and accurate estimates of the moisture used by the crop were impossible.

In the soil moisture sampling, two rows of samples, 30 to 100 yards apart, were taken across each field or strip from one hedge to the other.

TABLE 7—STORED MOISTURE USED BY WHEAT CROP, CONQUEST, 1950-54

Distance from shelterbelt	1950	1951	1952	1953	1954	Mean
ft.	in.	in.	in.	in.	in.	in.
West side of field						
15	4.5	4.3	7.9	4.1	0.4	4.2
30	4.0	2.5	6.3	5.0	0.3	3.6
45	4.1	2.1	6.1	5.1	0.2	3.5
75	3.0	1.1	5.9	2.8	−0.2	2.5
120	2.9	0.4	5.5	3.3	−0.6	2.3
165	2.3	0.5	5.1	2.7	−0.2	2.1
Centre	3.0	1.6	4.8	2.2	−0.7	2.2
East side						
165	2.6	−0.9	4.1	3.3	−1.0	1.6
120	2.8	0.1	4.8	1.8	−1.3	1.6
75	2.5	0.1	5.1	3.5	0.3	2.3
45	3.5	2.6	6.2	3.4	−0.3	3.1
30	5.4	4.5	7.3	4.2	0.4	4.4
15	5.9	2.0	7.4	6.0	1.2	4.5

Samples were taken at distances of 15, 30, 45, 75, 120, 165 and 300 feet from each hedge. At each distance soil moisture samples were taken in depths 0-6, 6-12, 12-24, 24-36 and 36-48 inches in medium loam soil, and an additional sample, 48-60 inches, was taken in sandy loam. Moisture samples were taken twice a year, at seeding time and at harvest. The volume weight of the soil was determined so that the percentage moisture in the samples could be converted to inches of water. The difference between the moisture content at spring and at harvest gave the amount of water removed from the soil by evapotranspiration during the season.

TABLE 8—STORED MOISTURE USED BY WHEAT CROP, ANEROID, 1950-54

Distance from hedge	1950	1951	1952	1953	1954	Mean
ft.	in.	in.	in.	in.	in.	in.
West side of field						
15	7.5	5.2	4.7	6.4	4.0	5.6
30	6.9	5.0	5.0	6.7	4.7	5.7
45	6.8	2.8	4.6	7.4	4.0	5.1
75	2.6	3.4	4.2	6.5	4.3	4.2
120	1.6	2.3	3.7	6.1	3.6	3.5
165	1.6	2.3	3.3	6.8	3.7	3.5
Centre	1.7	2.0	2.6	5.2	4.4	3.2
East side						
165	1.7	1.8	3.7	4.8	4.1	3.2
120	1.6	2.3	3.4	5.2	3.8	3.3
75	1.6	3.7	3.0	5.9	4.3	3.7
45	2.6	5.9	4.1	5.5	4.5	4.5
30	6.3	6.9	4.4	5.4	3.7	5.3
15	5.9	5.6	3.8	4.9	4.3	4.9

TABLE 9—SUMMARY OF GRAIN YIELDS, ANEROID, 1950-54

Distance from hedge	1950	1951	1952	1953	1954	Total	Mean
ft.	bu./ac.	bu./ac.	bu./ac.	bu./ac.	bu./ac.	bu./ac.	bu./ac.
West side of field							
15	17.7	35.0	34.0	20.9	26.6	134.2	26.8
30	20.6	31.2	34.8	23.2	27.5	137.3	27.5
45	18.3	26.6	32.4	22.7	26.7	126.7	25.3
75	20.5	26.3	30.5	22.3	26.5	126.1	25.2
120	16.1	20.8	23.2	20.4	26.1	106.6	21.3
165	15.3	21.8	25.3	20.0	25.6	108.0	21.6
Centre	14.2	18.7	21.2	19.3	25.4	98.8	19.8
East side							
165	15.1	20.2	24.9	17.8	25.9	103.9	20.8
120	14.6	19.0	23.5	17.6	24.0	98.7	19.7
75	14.4	26.2	23.9	18.7	25.5	108.7	21.8
45	17.8	33.1	28.5	18.0	25.9	123.3	24.7
30	18.6	35.6	33.5	17.0	26.6	131.3	26.3
15	19.8	33.6	36.1	17.0	26.0	132.5	26.5

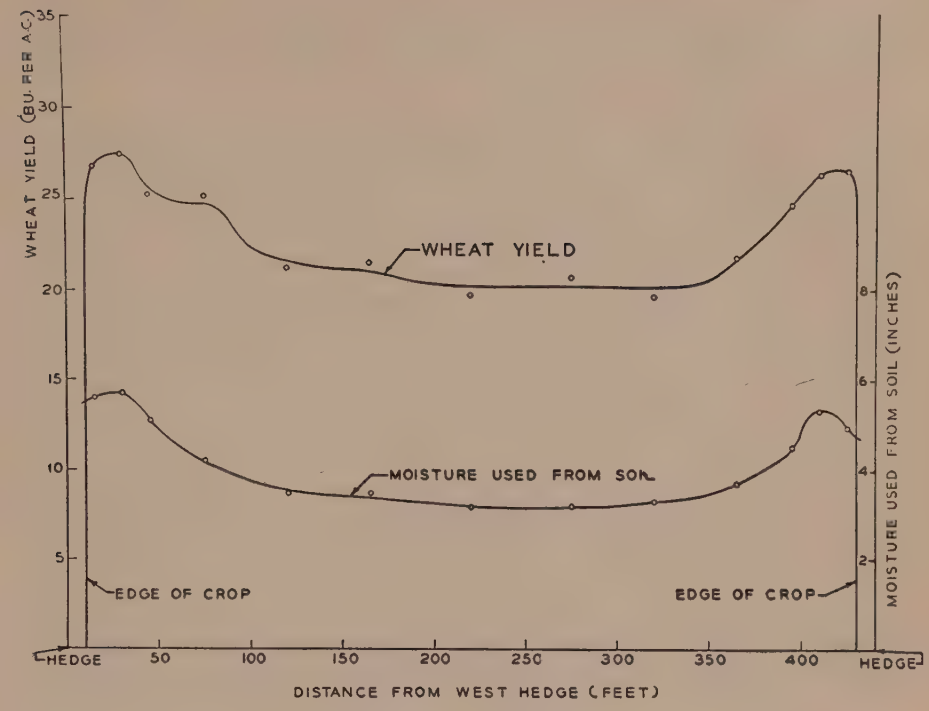

FIGURE 1. Wheat yield and stored moisture used between hedges, Aneroid, 1950-54.

Rainfall records were obtained near each of the sampled fields so that the seasonal rainfall could be added to the water used from the soil to give the total water used by the crop.

At harvest time square-yard samples of crop were taken in five rows across each field at the same distances as the soil moisture samples. Two of the crop sampling rows coincided with those sampled for soil moisture. The rows were chosen at sites as level as possible across the strips, and they were distributed over approximately one-quarter mile along the hedges. The crop samples were cut close to the ground, and yields were recorded both as total crop and grain.

The quantities of moisture used from the soil by wheat crops at the Conquest and Aneroid projects for the five years 1950-54 are given in Tables 7 and 8 respectively. In general, the soil moisture content near the shelterbelts was higher than in the centre of the fields and this resulted in greater use of moisture by the crop growing adjacent to the trees. Usually the soils at all points in the fields were dried to near the wilting percentage by harvest. The areas of increased soil moisture use corresponded roughly with those occupied by snow drifts in the winter. The differences in moisture use across the strips were most marked in the first three years of the test, when the snowfall was greater, and the seasonal rainfall less, than was received in 1953 and 1954. The results for Aneroid show more uniform trends across the strips than do those for Conquest. The mean moisture

use from soil at Aneroid for the 5-year period is plotted in the lower half of Figure 1. This shows the rapid drop in moisture use between 45 and 75 feet from the hedges.

Crop yields obtained at Aneroid for the period 1950-54 are given in Table 9. The yields were high near the hedges and tapered off toward the centre of the fields in the same way as did the moisture use. The differences across the strips were greatest in the first three seasons when increased yields up to 15 bushels per acre occurred near the hedges.

Damage to crops due to sapping of moisture by tree roots was not appreciable, as it did not extend much beyond the height of the trees. The hedge rows were usually cultivated 6 to 8 feet outside the tree branches, and diminution of the crop was barely noticeable beyond the cultivated strip. Peak yields were usually observed 15 to 20 feet from the hedges.

The close relationship between soil moisture used and wheat yield at Aneroid is shown in Figure 1, where wheat yields across sheltered strips are given in the upper curve. The mean increase in yield for the five-year period was 0.7 bushel per acre on a 27-rod strip. This value was obtained by distributing and weighting the increases near the hedges across the whole strip, taking into account the area occupied by the tree rows.

The above result was obtained assuming that the yields in the centre of sheltered fields were comparable to those in exposed fields. During the first few years of the project, samples were taken from exposed sites as well as from sheltered fields in an attempt to check this point. The differences between soils, methods of cultivation, dates of seeding and weed growth made it impossible to establish small differences between yields in sampling a reasonable number of fields. It is believed, however, that measurements of microclimatic factors such as wind velocity and evaporation should show whether environmental conditions influencing the growth of crops are different at the centres of fields within the shelterbelt project than those outside. The results thus far indicate that any such differences must be very small, particularly in fields bordered with single row caragana.

The gain in crop yield due to snow near shelterbelts is greatest in years of ample snowfall when winter winds have blown exposed areas bare. Sheltered fields show little net gain from snow when the soil is saturated by autumn or spring rains, when the snowfall is well below average, or when the winds are light and the snow holds well on the fields.

The shelterbelt influence on yield is more striking in dry than in wet seasons such as experienced in the past five years. The areas of increased yield remain about the same, but the yield near the shelter is greater relative to that in the centre of the field or in exposed sites. For instance, in the dry seasons, 1936 to 1938, crops were harvested in strips along shelterbelts when those in exposed areas were a total failure. It seems probable that this high relative gain was due as much to the distribution of the soil moisture as to a net gain in moisture in the fields as a whole, that is to say, the snow accumulated in drifts near the shelterbelts at the expense of the central area between the tree strips. The wheat crop requires 5 inches of water before any grain is produced (7), and, even with 7 inches or more,

the crop might not be worth harvesting. However, if an additional inch or two of moisture were accumulated near the shelterbelt, it could be used with greater efficiency and good yields would result.

ACKNOWLEDGEMENTS

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RAISING DAIRY CALVES WITH A LIMITED AMOUNT OF MILK[1]

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ABSTRACT

An experiment was conducted, using three lots of 11 Holstein heifer calves, to compare their relative growth rates when fed whole milk to approximately 4 weeks of age, followed by either a calf starter (with and without aureomycin) or skimmilk to 16 weeks of age. The calf starter contained approximately 21 per cent protein, all of plant origin. The calves fed skimmilk received a grain mixture containing approximately 15 per cent protein. The calf starter and grain mixture was limited to a maximum of 5 lb. per head daily. Good quality alfalfa hay was fed ad libitum. After 16 weeks of age all calves received alfalfa hay or pasture and a grain mixture (5 lb. per day) until one year of age. At 16 weeks of age the calves fed skimmilk were significantly heavier (when correction was made for differences in birth weights) than the calves fed calf starter. The addition of aureomycin to the calf starter had no effect on the average body weights at 16 weeks of age. There were no differences in height at withers or heart girth measurements at 16 or 52 weeks of age between the three lots; nor were there any differences in average body weights at 52 weeks of age. All lots were heavier at 16 and 52 weeks of age than the "Beltsville" standard (2).

On dairy farms where all fluid milk is marketed, skimmilk normally is not available for the raising of heifer calves for herd replacements. Under this system the use of whole milk or whole and skimmilk for calves is costly. In view of this, efforts have been made during the past number of years by many investigators to formulate milk substitutes and calf meals that would replace most of the milk used for raising calves.

A study was undertaken at Lethbridge, Alberta, to determine whether Holstein heifer calves would make normal growth when weaned from whole milk between 3 and 4 weeks of age and fed alfalfa hay and a high protein calf starter formulated without the use of skimmilk powder or other animal proteins. These calves were compared with similar ones weaned from whole milk at the same age and then fed skimmilk along with alfalfa hay and a grain mixture. The value of adding aureomycin to the calf starter also was studied.

Norton and Eaton (3), on the basis of studies involving 24 calf starters and over 300 calves, concluded that "the Cornell limited-whole-milk and dry-calf-starter method of raising calves where weaning is at 7 to 10 weeks of age, depending upon the breed, will produce gains in calves well above the established normals". In these studies the calves received approximately 350 lb. of whole milk. The authors found that protein of animal origin was not essential in the calf starter but that quality of hay was important.

Wallace *et al.* (6), in studies conducted to formulate substitutes for whole milk after the calves were 10 to 14 days of age, found that approximately normal growth was obtained from mixtures containing large amounts

[1] Contribution from the Division of Animal Husbandry, Experimental Farms Service, Canada Department of Agriculture, Ottawa.

[2] Animal Nutritionist and Animal Husbandman, respectively.

of dried milk solids. In general, the calves raised on milk substitutes were rougher in appearance from the third to seventh week of age, and their growth rate was somewhat slower during the first month, than the calves raised on whole milk. However, no differences were evident by 4 to 6 months of age.

Many papers have been published on the value of including aureomycin or other antibiotics in milk replacers and calf starters. Reid *et al.* (5) have reviewed the information available to the end of 1953. Most of this information indicates that the addition of aureomycin or terramycin produced an increase in growth rate and in feed efficiency during the first 6 months after birth. Penicillin was found to retard growth in some cases. The feeding of an antibiotic to young calves appears to have been most beneficial in those herds where calf scours or other infectious diseases were prevalent.

PROCEDURE

Thirty-three Holstein heifer calves, born between 1952 and 1954 at the Experimental Farm, Lethbridge, were used in this study. Each calf was assigned at random to one of three lots, with the restriction that each lot contain an equal number of calves from first-calf heifers and from mature cows. All calves were left with their dams for 3 days after birth and then trained to drink from a pail. They were kept in individual pens until 16 weeks of age. All calves received whole milk at the rate of approximately 10 per cent of their body weight until they were 21 days of age. At that time the quantity of whole milk was reduced by approximately 10 per cent each day so that by the time they were 30 days of age they were receiving no whole milk. Alfalfa hay and water were available to the calves at all times.

Skimmilk replaced whole milk for the calves in Lot 1. This was fed, until 16 weeks of age, at 10 per cent of body weight to a maximum of 15 lb. per head daily. In addition, from one week of age, the calves received a concentrate mixture (calf grower) composed of 68 lb. of oats, 10 lb. of barley, 10 lb. of wheat bran, 10 lb. of linseed meal, 1 lb. of salt (cobaltized) and 1 lb. of bonemeal. This mixture contained approximately 14.8 per cent protein, 5.9 per cent fat, and 9.4 per cent fibre. It was fed free choice until a consumption of 5 lb. per head daily was reached and thereafter consumption was limited to this amount.

The calves in Lot 2 received no milk after 30 days of age. Commencing at approximately one week of age, and continuing until 16 weeks of age, a concentrate mixture was available to the calves at all times. The mixture was composed of 32 lb. of oats, 5 lb. of barley, 10 lb. of wheat, 10 lb. of wheat bran, 10 lb. of linseed oilmeal, 17.5 lb. of soybean meal, 5 lb. of alfalfa meal, 8 lb. of molasses, 2.5 lb. of mineral mixture, 80,000 I.U. of vitamin A, 16,000 I.U. of vitamin D, and 50 mg. of riboflavin. This calf starter contained approximately 21.0 per cent protein, 4.2 per cent fat, and 9.6 per cent fibre. Consumption was limited to a maximum of 5 lb. per head daily.

The mineral mixture included above contained 40 lb. of bonemeal, 20 lb. of ground limestone, 40 lb. of salt, 2 gm. of cobalt sulphate, 4 gm. of copper sulphate, and 40 gm. of ferrous sulphate.

The calves in Lot 3 were fed the same as those in Lot 2, except that each 100 lb. of starter contained ½ lb. of Aurofac 2A* (contains at least 3.6 gm. aureomycin and approximately 1 mg. of vitamin B_{12} per lb.).

After 16 weeks of age all calves were placed in groups of four to six, depending on age. The calves that reached 16 weeks of age during the summer months were turned on to pasture, while those that reached 16 weeks of age during the fall and winter months were continued on alfalfa hay. In addition, each calf received, until one year of age, 5 lb. per day of the concentrate mixture fed to Lot 1.

All calves were weighed at birth and at 7-day intervals until 16 weeks of age, and thereafter at 2-week intervals until one year of age. Height at withers and heart girth measurements of the calves were taken at each weighing.

During 1952 the concentrate mixtures were fed in the ground form but commencing in December, 1953, they were fed in the pelleted form.

* The Aurofac 2A used in this experiment was generously supplied through the courtesy of R. F. Elliott, Lederle Laboratories, Pearl River, N.Y.

TABLE 1.—AVERAGE BODY WEIGHTS, HEIGHT AT WITHERS, AND HEART GIRTHS OF DAIRY CALVES AT DIFFERENT AGES AS INFLUENCED BY RATION

	Lot 1 Skimmilk	Lot 2 Calf starter	Lot 3 Calf starter + aureomycin
Body weights (lb.)			
Birth	84.1 ± 10.0[1]	87.6 ± 11.5	86.5 ± 9.5
4 weeks	113.8 ± 13.5	117.1 ± 12.6	117.1 ± 16.2
8 weeks	163.0 ± 19.3	159.9 ± 17.5	157.5 ± 25.0
12 weeks	221.7 ± 29.0	208.8 ± 23.6	210.5 ± 28.2
16 weeks	286.3 ± 32.7	267.8 ± 28.8	263.8 ± 27.9
52 weeks	758.0 ± 61.0	718.0 ± 68.0	735.0 ± 71.0
Height at withers (in.)			
Birth	28.2 ± 1.7[1]	28.5 ± 1.5	28.6 ± 1.5
4 weeks	30.6 ± 1.6	30.6 ± 1.5	30.8 ± 1.4
8 weeks	32.7 ± 1.7	32.8 ± 1.0	32.2 ± 1.4
12 weeks	34.9 ± 1.8	34.4 ± 1.5	34.3 ± 1.5
16 weeks	37.1 ± 1.5	36.1 ± 1.5	36.1 ± 1.3
52 weeks	47.2 ± 1.2	47.0 ± 1.4	47.2 ± 1.1
Heart girth (in.)			
Birth	29.9 ± 2.2[1]	29.9 ± 1.2	30.0 ± 1.4
4 weeks	32.9 ± 1.3	32.9 ± 1.5	32.8 ± 1.7
8 weeks	36.5 ± 1.8	36.1 ± 1.4	36.0 ± 2.1
12 weeks	40.1 ± 2.0	39.0 ± 1.8	39.4 ± 2.3
16 weeks	43.8 ± 2.2	42.6 ± 1.6	42.4 ± 1.6
52 weeks	62.9 ± 2.5	61.6 ± 2.2	62.2 ± 1.8

[1] Standard deviation.

TABLE 2.—AVERAGE FEED CONSUMPTION (LB.) PER CALF TO 16 WEEKS OF AGE AS INFLUENCED BY RATION

	Lot 1 (Skimmilk)	Lot 2 (Calf starter)	Lot 3 (Calf starter + aureomycin)
To 4 weeks of age[1]			
Whole milk	234	235	232
Skimmilk	25	—	—
Concentrate	5	10	8
Alfalfa hay	5	5	4
From 4 to 8 weeks of age[1]			
Skimmilk	358	—	—
Concentrate	29	76	73
Alfalfa hay	32	26	28
From 8 to 16 weeks of age			
Skimmilk	858	—	—
Concentrate	184	249	257
Alfalfa hay	142	134	126
Total to 16 weeks of age			
Whole milk	234	235	232
Skimmilk	1216	—	—
Concentrate	218	335	338
Alfalfa hay	179	165	158

[1] Whole milk was fed to 30 days of age, but is included in that fed to 4 weeks of age.

RESULTS AND DISCUSSION

The average body weights, height at withers, and heart girth measurements taken at birth, 4 weeks, 8 weeks, 12 weeks, 16 weeks, and 52 weeks of age, and the average feed consumption data, are shown in Tables 1 and 2. The average body weights at weekly intervals for all lots are plotted in Figure 1.

Although the calves fed skimmilk (Lot 1) made somewhat faster gains to 16 and 52 weeks of age than those fed the calf starter (Lots 2 and 3) an analysis of variance indicated that these differences were not significant ($p = 0.05$). However, when the weights at 16 and 52 weeks of age were adjusted for differences in initial weights by analyses of covariance, the calves in Lot 1 were significantly heavier ($p < 0.01$) at 16 weeks but not at 52 weeks of age than the calves in Lots 2 and 3. There were no differences in body weights between Lots 2 and 3 after adjusting for differences in initial weights.

The within-lot correlation between birth weight and weights at 16 and 52 weeks of age were $+0.78$ and $+0.60$, respectively. For each pound increase in birth weight there was an increase of 2.2 pounds at 16 weeks and 3.8 pounds at 52 weeks of age.

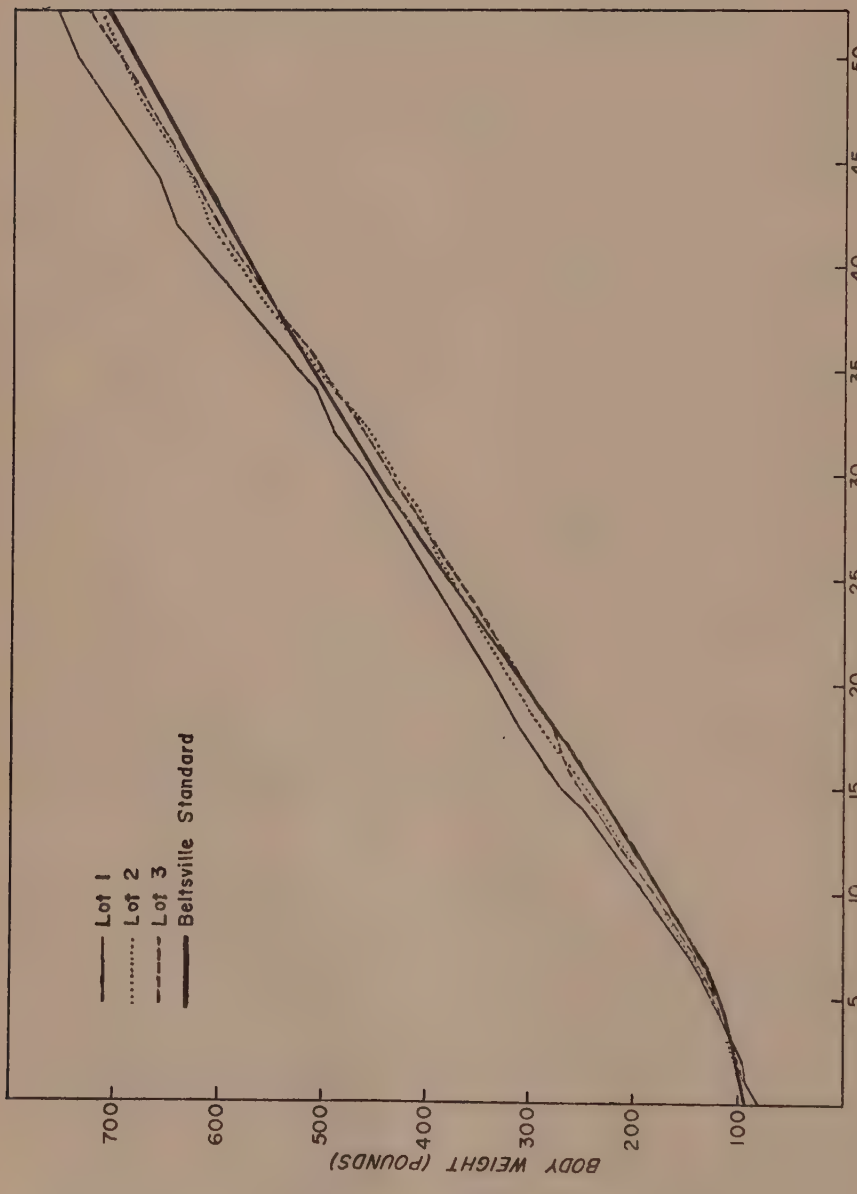

FIGURE 1. Average body weights of the 3 lots of calves to one year of age in comparison with the "Beltsville" standard (2).

Analyses of variance and covariance of the data on height at withers and heart girth measurements indicated that there were no significant differences between the three lots at 16 or 52 weeks of age when corrected or not corrected for differences in these measurements at birth.

The average body weights for each of the three groups were lighter at birth than the "Beltsville" (2) growth standards for Holstein heifer calves but at 16 and 52 weeks of age the calves in Groups 2 and 3, fed no milk after 4 weeks of age, were approximately 6 and 2 per cent heavier, respectively, than the "Beltsville" standard. This would indicate that the growth rate of the calves receiving no milk after 4 weeks of age was above average for Holstein heifer calves. However, it will be noted from Figure 1 that the average body weights of the calves in Lots 2 and 3 were less than the "Beltsville" standard between approximately 22 to 36 weeks of age. The data used in the "Beltsville" growth standard represented that of 400 calves which had received whole milk to 4 weeks of age, skimmilk to 6 months of age, a maximum of 3 lb. of grain per head daily, and alfalfa or mixed hay ad libitum. The growth rate to one year of age in the "Beltsville" growth standard for Holstein heifer calves is approximately 11 per cent greater than that in the commonly-used "Ragsdale" growth standard (4).

Height at withers and heart girth measurements of the calves in Lots 2 and 3 were similar at 16 weeks to the "Ragsdale" standard but approximately 2 to 3 per cent greater at one year of age. (The "Beltsville" growth standard does not include heart girth or height at withers measurements).

It will be noted in Table 2 that the consumption of concentrate and hay was low before 4 weeks of age in all lots. However, as soon as the calves in Lots 2 and 3 were taken off milk their concentrate consumption increased rapidly. During the 4-8 week period they consumed an average of 2.7 lb. of calf starter and 1.0 lb. of hay daily and during the 8 to 16 week period they consumed 4.5 lb. of calf starter and 2.3 lb. of hay. The calves fed skimmilk (Lot 1) consumed about the same amount of hay as those in Lots 2 and 3 but only two-thirds the amount of concentrate.

The addition of aureomycin to the calf starter resulted in no improvement in growth. This fact does not agree with that in most of the published literature (5) on the feeding of aureomycin to young calves but does agree with some findings (1). However, it should be mentioned that calf scours has not been a problem in the herd at this Farm. This may explain the lack of response to aureomycin.

A number of investigators who have studied the use of dry calf starters have emphasized that calves should be encouraged to eat the starter at an early age and before milk is discontinued. In this study there was a highly significant correlation ($r = 0.74$) between the amount of hay and calf starter consumed to 6 weeks of age and the weight of the calf at 16 weeks of age. For each additional pound of feed (hay or starter) that the calf consumed to 6 weeks of age the body weight was increased by 1.4 pounds at 16 weeks of age. However, the weight of the calf when milk was discontinued was also an important factor in determining the amount of

feed that it would eat as a highly significant correlation was obtained ($r = +0.70$) between the weight of the calf when the amount of milk fed was reduced (i.e. 3 weeks of age) and the consumption of hay and starter to 6 weeks of age. For each pound increase in weight at 3 weeks of age the calf consumed 0.9 lb. more feed per day to 6 weeks of age. When weight of calf at 3 weeks of age was held constant by the analyses of partial regression, each additional pound of feed consumed to 6 weeks of age increased its weight 0.5 pound at 16 weeks of age.

The results of this experiment indicate that healthy Holstein heifer calves can be taken off milk at 4 weeks of age and raised successfully on a calf starter made up without the use of animal proteins. Whether certain ingredients in the calf starters used were essential, and whether less whole milk can be fed without adversely affecting growth, will be studied in future experiments.

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FLOWER COLOUR INHERITANCE IN DIPLOID AND TETRAPLOID ALFALFA[1]

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ABSTRACT

Crosses between purple- and yellow-flowered diploid alfalfa plants belonging to *Medicago sativa* L. and *M. falcata* L. were studied to determine the number and interaction of genes necessary for pigment production. At the tetraploid level inheritance patterns were studied in intraspecific and interspecific crosses in an effort to determine whether alfalfa is of autotetraploid or of allotetraploid origin.

The purple colour was found to be due to a sap-soluble anthocyanin pigment, the production of which was conditioned by two complementary genes. In the absence of either of these *M. sativa* flowers are white. All seven *M. falcata* parents used in this study carried one of these two genes. Yellow colour was attributed to two unrelated pigments, a sap-soluble anthoxanthin and a plastid-residing carotene. Production of the yellow pigments was dependent on several genes, the effects of some of which were quantitative and of other qualitative. The intensity of purple pigmentation appeared to be controlled to some extent by intensification factors but it also appeared probable that the number of dominant alleles present at the complementary loci was also a determining factor.

Both disomic and tetrasomic patterns of inheritance were noted. One of the two factors associated with the production of purple pigment appeared to follow a tetrasomic pattern exclusively, whereas the second factor followed a disomic pattern in some plants and a tetrasomic in others. In some families showing wide ratios of the order of 1:100 it was not determined whether the small number of non-purple segregates was due to disomic segregation of triplicate factors or to a semi-random type of pairing. The data are interpreted as providing evidence that alfalfa is of ancient autotetraploid origin but that it has undergone sufficient differentiation in some of its chromosomes to permit of disomic inheritance patterns replacing to some extent the original tetrasomic patterns.

Flower colour has provided a convenient character for the study of inheritance in alfalfa. A number of papers have been published by interested workers in Canada and the United States of America but the results have been conflicting and no completely satisfactory interpretation has emerged. This paper reports an attempt to explain flower colour inheritance in alfalfa through a study of the segregation of purple and yellow pigments at both diploid and tetraploid levels.

LITERATURE REVIEW

Until 1951 the results of nearly all genetic analyses in alfalfa had been interpreted on a disomic basis although evidence of autotetraploid characteristics had been noted, especially in the cytological field. A review, in that year, by Atwood and Grun (2) provided a comprehensive summary of the literature which existed up to that time on the cytogenetics of alfalfa. Information in the field of autotetraploid genetics had been accumulating in the meantime and in 1945 Little (12) reviewed the literature on this

[1] Contribution from the Dominion Forage Crops Laboratory, Saskatoon, Sask., being a condensation of a thesis submitted to the Faculty of Graduate Studies of the University of Saskatchewan in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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topic. However, no definite evidence of tetrasomic segregation in alfalfa was furnished until 1950 when Oldemeyer (14) concluded his study on the inheritance of seed coat colour. He noted that, while intraspecific sativa* crosses appeared to segregate in a disomic manner, crosses between these same sativa parents and autotetraploid falcata parents which had been developed by colchicine treatment of diploid falcata plants segregated as autotetraploids. A year later, Stanford (17), investigating the genetics of the purple pigmentation of alfalfa flowers, used F_3 data to demonstrate tetrasomic inheritance and to estimate the frequency of double reduction, a phenomenon associated with the formation of quadrivalents. In a later paper by the same author further evidence of the autotetraploid nature of alfalfa was provided (18).

The genetics of flower colour in *Lathyrus odoratus* L., which belongs to the same family as alfalfa, has been investigated by a number of British workers including biochemists as well as geneticists. The cross between two white-flowered strains of sweet pea, studied by Bateson (3), provided the first known example of complementary gene action and later reports by Haldane (8), by Beale, Robinson, Robinson and Scott-Moncrieff (4) and by Scott-Moncrieff (16) provided further information on the specific physiological action of many of the genes associated with the varied colours of the sweet pea flowers. These later workers not only confirmed Bateson's theory of complementary gene action for anthocyanin production but identified the main pigment as malvin. They also identified two genes for anthoxanthin production, two for anthocyanin intensification and three for anthoxanthin intensification. In addition they demonstrated the existence of oxidizing and acidifying genes responsible for colour change.

MATERIALS AND METHODS

The parental material used in this study included white-, yellow- and purple-flowered tetraploid (2n = 32) plants and yellow and purple diploids. The plants S-42-63 and S-43-45 had pure white flowers, white buds, and seeds that were nearly white. Plants S-42-58 and S-42-60 likewise had pure white flowers but the flower buds carried a very slight trace of pink pigment in their tips. The crown buds of this second pair were also slightly pinkish and their seeds were yellow. S-42-182 was purple flowered. S-43-21 was a yellow-flowered selection, a typical representative of the species *Medicago falcata* L. The parent designated as 13-11 carried purplish-yellow or greenish flowers and was the product of a *M. sativa* x *M. falcata* cross. All of these were tetraploids.

Of the diploid (2n = 16) parents, S-45-2, S-45-3, S-45-5, S-45-48, 157-60 and 154-10 were yellow-flowered falcata plants and the S-49 lines were purple-flowered sativa types. All falcata-type parents, diploid and tetraploid, had bright yellow flowers showing no trace of purple either in the bud or in the open flower and all the purple sativa parents were completely free of yellow pigment.

Most of the plants used in this study as parental material had already been identified as either diploid or tetraploid but where this had not been done the plant was examined cytologically. The procedure employed was the acetocarmine root-tip smear technique outlined by Greenshields (7).

*Frequently in this paper the species names of alfalfa have been used as adjectives.

The difference in flower colour of the parents usually provided an easy means of determining whether the progeny was the result of cross- or self-pollination. Wherever in the crossing program this criterion was not applicable the female parent was emasculated by clipping the standard, tripping the flower and blowing off the pollen. This procedure was highly effective as revealed in crosses where the results could be evaluated. Selfing was induced by bagging the unopened raceme and, at a later date, removing the bag, tripping the flower with a toothpick and replacing the bag. In much of the material the more common practice of rolling the bag between the hands proved ineffective. In selfing done in the greenhouse during the winter months no bagging was necessary.

Nearly all the tetraploid material was sufficiently self-fertile to provide all the self seed required but most diploid plants proved to be highly self-sterile and this was most noticeable among the yellow-flowered segregates. The result was that nearly all diploid families were undesirably small and it was only by constant attention to selfing the early group of hybrid plants over a period of many months that a sufficient number of seeds was obtained to enable segregation trends to be detected. Since self-sterility in those F_2 plants selected for further study was even more pronounced the F_3 population was very small. This difficulty was partially overcome a year or two later when, by a search through a larger diploid population, a few F_1 plants were located each of which produced over 100 seeds following self-pollination of a large number of flowers.

Because of a desire to compare synthetic polyploids with the natural type an effort was made to induce doubling of the somatic chromosome number of both diploid and tetraploid material. The method used, that recommended by Lesins*, proved to be reasonably effective. Seedlings, 3 to 5 days old, were treated at a stage of growth when the cotyledons had spread apart but before the first or unifoliate leaf had emerged. They were inverted and placed so that the plumules were immersed in a 0.05 per cent colchicine solution with the roots projecting above and free from the solution. The roots were kept moist by means of dampened cotton batting. At the end of 12 hours the seedlings were removed, washed thoroughly in running water for several minutes and then planted in the greenhouse flats.

In this study an exhaustive analysis of alfalfa flower pigments was not attempted but a few flower types, both purple and yellow, were investigated by methods reported by Robinson and Robinson (15) and by Bonner (5). The main purpose was to determine to which class the pigment belonged rather than to categorically identify it. Most of the plant pigments belong to either of two general types. The members of the one group, being water soluble, are located in the cell sap. They consist of the anthocyanins which range in colour from red to blue, and the chemically related anthoxanthins which are yellow. In the other group are the carotenoids, soluble in certain organic solvents but not in water. They, too, consist of two subgroups, the carotenes which are soluble in petroleum ether, and their derivatives, the xanthophylls, which are soluble in alcohol. The carotenoids or plastid pigments are frequently yellow in colour and hence may be confused with the anthoxanthins.

*Personal communication.

As a part of the study, the relative quantity of anthocyanin present in some of the purple segregates was determined and related to the amount found in the parents. For this analysis the major portion of the standard of 16 freshly opened flowers was clipped off and partly macerated in 5 millilitres of a 1 per cent hydrochloric acid solution. The extraction of the anthocyanin was usually complete less than 20 hours later and the extract, free from all solid particles, was analysed for anthocyanin content in the spectrophotometer. The instrument readings, based on a value of zero for the pure solvent, were proportional to the amount of anthocyanin pigment present in the solution and ranged from about 25 for the white flower extract to over 1000 for some of the darker purples. Repeated tests on the same plant indicated that the variation due to the sampling technique rarely exceeded 10 per cent. The yellow pigment was more difficult to extract and to separate from other cellular material and no simple, rapid procedure, suitable for making quantitative tests for this pigment in large numbers of plants, was found. Classification of the segregating populations was based on either of two criteria, colour or intensity, and thus was directly or indirectly related to the results of the qualitative and quantitative tests referred to above.

In the diploid F_2 population resulting from falcata-sativa crosses segregation classes of the kinds listed below were recognized:

(a) Yellow-flowered plants with no trace of purple either in the bud or in the open flower stage. Within this group, as in *(b)* below, appeared plants with various intensities of the yellow pigmentation, capable of being allocated somewhat arbitrarily to distinct classes.

(b) Yellow-flowered plants showing at the tip of the bud a visible amount of anthocyanin pigment which, however, disappeared before the flower opened. Groups *(a)* and *(b)* were combined and classed as yellow or as non-purple.

(c) Purple-flowered plants with no visible trace of yellow.

(d) Green-flowered plants in which both the purple and the yellow pigments were present. This group showed wide variation both in the total depth of pigmentation and in the relative proportion of the pigments. The flowers were invariably purple in the bud stage and often in the early flower stage. As they aged they gradually changed first to green, then to greenish-yellow and in some instances to a smudgy yellow. No attempt was made to assort these into separate classes. Group *(c)* and *(d)* were combined where applicable and classed as purple or purplish.

The types of tetraploid crosses that were studied included white × white, white × yellow, white × purple, yellow × purple and some backcrosses. The segregates of these crosses included, in addition to classes *(a)* to *(d)* mentioned above, *white-flowered plants*, some of which had faintly pinkish bud tips.

In the classification of the parents and their progenies categorization was based mainly on visual observation of depth and shade of colour. The spectrophotometer was used for a more accurate measurement of the quantity of the purple pigment. This instrument, however, was employed mainly as a check since field inspection usually was sufficient. Because no simple means was found of extracting fully the yellow pigment found in the falcata plants and their progenies, classification of these was based entirely on visual inspection in the field.

EXPERIMENTAL RESULTS

Pigments of Alfalfa Flowers

Petals obtained from representative purple-flowered plants yielded a reddish-violet solution on extraction with 1 per cent hydrochloric acid. Qualitative tests indicated that the purple colour was due to the anthocyanin pigment malvin. No other anthocyanin pigment was detected in these flowers but the flowers of a different shade of purple, violet or blue may possibly be found to contain other members of the anthocyanin series.

The yellow colour of *M. falcata* flowers was found to be due to two unrelated yellow pigments. One was insoluble in water but soluble in acetone and petroleum ether. It was identified as the plastid pigment carotene. The other, originally discovered by Lesins*, was extractable only by hot water. It was presumed to be one of the sap-soluble anthoxanthin pigments.

Segregation for Purple Pigment in Diploid Families

Several parents of both the sativa and the falcata types were used in making the diploid crosses and some of these have since been lost, either through disease or winter injury. Consequently, an exact description of each parent cannot be given. It may be noted that some variation existed in the depth of pigmentation of the purple-flowered parents whereas very

*Personal communication.

TABLE 1.—SEGREGATION FOR PURPLE PIGMENT IN THE F_2 GENERATION OF PURPLE-YELLOW-FLOWERED DIPLOID CROSSES (TYPE 1)

Cross	Number of families	Purple or purplish-yellow	Non-purple (yellow)	Total
S-49-135 x S-45-5	4	84	30	114
S-49-135 x 157-60	1	12	2	14
S-49-138 x S-45-2	1	8	1	9
S-49-139 x 154-10	1	10	5	15
S-49-139 x S-45-3	1	24	6	30
S-49-154 x S-45-48	3	69	29	98
S-49-161 x 157-60	1	22	6	28
Observed—total		229	79	308
Expected (3:1)		231	77	308
$X^2 = 0.07$		D.F. = 1	$0.8 > P > 0.7$	

TABLE 2.—SEGREGATION FOR PURPLE PIGMENT IN THE F_2 AND F_3 GENERATIONS OF PURPLE- X YELLOW-FLOWERED DIPLOID CROSSES (TYPE 2)

Cross	Generation	Purple or purplish-yellow	Non-purple (yellow)	Total
S-49-135 x S-45-3	F_2	5	4	9
S-49-142 x S-45-3	F_2	7	4	11
S-49-139 x S-45-3	F_2	8	6	14
S-49-139 x S-45-3	F_3	4	3	7
Observed—total		24	17	41
Expected (9:7)		23	18	41
$X^2 = 0.1$		D.F. = 1	$0.8 > P > 0.7$	

little or no variation was shown by the several yellow-flowered parents. The F_1 plants resulting from the sativa-falcata crosses also showed variation both between sibs and between lines indicating that some of the parental plants were not completely homozygous for all the factors affecting pigmentation. However, all F_1 plants were purplish-yellow. In the F_2 generation two segregation patterns were found. Twelve families provided a good fit to a 3 : 1 ratio and three to a 9 : 7 ratio. One F_3 family also segregated 9 : 7. Tables 1 and 2 show the results of the diploid crosses between purple- and yellow-flowered parents. All segregates bearing anthocyanin-containing flowers, whether they were purple or purplish-yellow (green), were grouped into one class and all those not containing anthocyanin (except in the tips of the buds) into the second class.

Most of the diploid hybrids are clearly segregating for one factor only but segregation for two factors complementary to each other is indicated by four related families all of which are descendants of the falcata parent, S-45-3. This plant also produced progeny which segregated 3 : 1. These results suggest it is heterozygous for one of the factors necessary for anthocyanin production and homozygous recessive for the other.

Two mutants were noted in the F_1 generation of these sativa-falcata diploid crosses. A yellow sector was found in a single petal of one plant and the flowers of an entire raceme were transformed to yellow in a second one. Both these mutations occurred in plants that otherwise bore purplish-yellow flowers. This loss through mutation of the ability to produce anthocyanin is comprehensible under either a monofactorial or a complementary factor hypothesis, and it emphasizes the qualitative nature of the factors responsible for anthocyanin production.

Segregation for Purple Pigment in Tetraploid Families

The four white-flowered tetraploid plants described previously, when intercrossed and when crossed with the yellow-flowered falcata plant, S-43-21, also provided evidence of complementary gene action. Table 3 shows the flower colour of the progeny when these plants were selfed or crossed.

TABLE 3.—BREEDING BEHAVIOUR OF WHITE-FLOWERED TETRAPLOID PLANTS

Parental treatment	Flower colour of F_1 or S_1 generation
White selfed	
S-42-58	white
S-42-60	white
S-42-63	white
S-43-45	white
White x white	
S-42-58 x S-42-60	white
S-43-45 x S-42-63	white
S-42-58 x S-43-45	purple
S-43-45 x S-42-60	purple
White x yellow	
S-42-58 x S-43-21	yellow
S-42-60 x S-43-21	yellow
S-42-63 x S-43-21	purplish-yellow
S-43-45 x S-43-21	purplish-yellow

These data reveal that the four white plants, although phenotypically alike in respect to flower colour, actually belonged to two different genotypic classes, S-42-58 and S-42-60 comprising one and S-42-63 and S-43-45 the other. They also show that the yellow-flowered plant S-43-21 carried one of the two complementary factors necessary for anthocyanin production. If these two genes are symbolized as C and P the two genotypic classes may be represented in skeleton form as follows:

ccccP – – –, S-42-58, S-42-60, S-43-21
C – – – pppp, S-42-63, S-43-45.

The quantitative results expected from the segregation of these two factors may be calculated on three different bases, namely, *(a)* that both factors follow the tetrasomic pattern; *(b)* that both follow the disomic pattern; *(c)* that one factor follows the tetrasomic and the other the disomic pattern. Table 4 shows for a number of typical genotypes the theoretical ratios expected for each of these three conditions.

An examination of Table 4 reveals a number of important features of these polyploid ratios. The first is that the completely heterozygous hybrid CcCcPpPp provides segregation ratios of 7.3 : 1, 17.3 : 1 and 10 : 1 according to whether the hybrid is an allotetraploid, an autotetraploid, or a combination of the two. The second feature is the close similarity of the disomic and tetrasomic ratios of 15 : 1 and 17.3 : 1. Clearly only a

TABLE 4.—THEORETICAL TETRAPLOID RATIOS FOR DISOMIC, TETRASOMIC AND DISOMIC-TETRASOMIC SEGREGATION PATTERNS WHERE CONTROL IS EXERCISED BY COMPLEMENTARY FACTORS

Parental Genotype	C—disomic P—disomic (allotetraploid)	C—tetrasomic P—tetrasomic (autotetraploid)[1]	C—tetrasomic P—disomic (auto-allo)
CcccPppp	9 : 7	9 : 7	9 : 7
CcccPPpp	3 : 1	2.7 : 1[4]	3 : 1
CcccPpPp	2.4 : 1[2]	2.7 : 1	2.4 : 1
CcccPPPp	3 : 1	3 : 1	3 : 1
CCccPppp	3 : 1	2.7 : 1	2.7 : 1
CCccPPpp	1 : 0	17.3 : 1[5]	35 : 1
CCcccPpPp	15 : 1	17.3 : 1	10 : 1[6]
CCccPPPp	1 : 0	35 : 1	35 : 1
CcCcPppp	2.4 : 1	2.7 : 1	2.7 : 1
CcCcPPpp	15 : 1	17.3 : 1	35 : 1
CcCcPpPp	7.3 : 1[3]	17.3 : 1	10 : 1
CcCcPPPp	15 : 1	35 : 1	35 : 1
CCCcPppp	3 : 1	3 : 1	3 : 1
CCCcPPpp	1 : 0	35 : 1	1 : 0
CCCcPpPp	15 : 1	35 : 1	15 : 1
CCCcPPPp	1 : 0	1 : 0	1 : 0

1. Here, as elsewhere in this paper, random chromosome segregation is assumed for calculation of autotetraploid ratios.
2. Close approximation to 45 : 19
3. Close approximation to 225 : 31
4. Close approximation to 105 : 39
5. Close approximation to 1225 : 71
6. Close approximation to 525 : 51

TABLE 5.—SEGREGATION FOR PURPLE PIGMENT IN FOUR TETRAPLOID F_2 FAMILIES

Cross	Observed segregation		Probability values for ratios		
	purple	non-purple	7.3 : 1	10 : 1	17.3 : 1
S-42-58 x S-43-45	162	12	0.04	0.3	0.4
S-42-60 x S-43-45	114	4	0.01	0.03	0.4
S-42-63 x S-43-21	109	7	0.05	0.25	0.8
S-43-45 x 157-60	129	6	0.01	0.05	0.5
Total	514	29	0.01	0.01	0.9

TABLE 6.—SEGREGATION FOR PURPLE PIGMENT IN TEST-CROSS PROGENIES

Test cross	Observed segregation		Probability values for ratios	
	purple	non-purple	3 : 1	5 : 1
S-42-58 x 13-11	37	5	0.05	0.4
S-42-60 x 13-11	169	29	0.01	0.4
Total	206	34	0.005	0.3

knowledge of the genotype of the parents would enable the research worker to differentiate between these two ratios. As a third item it may be noted that narrow ratios like 2.4 : 1, 2.7 : 1 and 3 : 1 are too nearly similar to permit of their differentiation in practice unless the family is large. Finally, even though it were possible to determine that a plant's progeny were segregating 3 : 1, it would still be impossible to tell whether the pattern was that of a diploid, an allopolyploid or an autopolyploid.

In addition to those listed in Table 3 a successful cross was made between one of the white-flowered types and a yellow-flowered diploid. The latter produced an unreduced gamete, apparently, as the F_1 was a tetraploid. It was purplish-yellow and fertile.

Table 5 shows the observed segregation for purple pigment when four anthocyanin-producing F_1 plants from some of the crosses mentioned above were selfed. In checking for goodness of fit only those ratios were tested which would result from F_1 plants heterozygous at all loci. Thus ratios of 35 : 1 and 15 : 1 were not considered as they would imply effective homozygosity (CCC– or C′C′––) at one locus, a rather unlikely possibility. The data indicate that in these four crosses one factor is segregating in a tetrasomic manner and the second either in a tetrasomic or a disomic manner, the latter alternative having much the smaller probability value.

A solution to the problem of which of the two factors is following a tetrasomic pattern can be reached by a study of Table 6. 13-11 is a hybrid plant produced by crossing purple- and yellow-flowered parents. It was used as a pollen parent in crosses with the two white-flowered plants S-42-58 and S-42-60. This hybrid plant, 13-11, presumably heterozygous for the factor C which the yellow-flowered parent lacked, was thus crossed to white parents which carried the recessive allele c. In effect it was a test

cross and the expected segregation ratio, depending on whether C adhered to the disomic or the tetrasomic pattern, was 3 : 1 and 5 : 1 respectively. The data strongly suggest that the C-locus is tetrasomic. S-42-58 was also crossed with the purple-flowered plant S-42-182 thus providing an F_1 heterozygous at the C-locus. The F_2 segregated 212 : 6. A satisfactory fit to these values is provided only by the tetrasomic ratio of 35 : 1.

The examples cited above indicate that the C-locus is tetrasomic in nature. They do not eliminate the possibility of a disomic behaviour for the P-factor although some of the data make it seem improbable. However a number of other crosses among which were some so arranged that it was the P-factor exclusively which was segregating were studied in the course of this investigation. In these, in marked contrast to those listed above, difficulty was encountered in classification. Although most of the segregates were either purple or white a few were so faintly tinged with purple as to be on the borderline between the two groups. The difficulty in classification was reflected in the variability of the probability values. Ratios such as 64 : 6, 201 : 3 and 115 : 1, representative of the types encountered, when tested for goodness of fit to 10 : 1, 15 : 1, 17.3 : 1, 35 : 1 and 63 : 1, usually provided a somewhat higher probability value for the disomic pattern than for the tetrasomic. Ratios such as 115 : 1 also suggest the possibility that an additional factor was influencing the results.

Segregation for Yellow Pigment in Diploid Families

Of the 342 F_2 plants arising from the purple × yellow diploid crosses only one individual appeared to be practically identical in flower colour with the type represented by the purple-flowered parents. Six other purplish plants carried at most a trace of yellow pigment. Approximately one-quarter of the F_2 population was yellow flowered but among these non-purple segregates none was white and none was as deeply pigmented as the yellow-flowered parents. The occurrence of only one non-yellow plant in a population of 342 suggests that three, four or five loci are involved in the production of yellow pigment.

The yellow segregates showed marked variation in depth of pigmentation and at a time when most of the plants were in flower an attempt was made to classify them on that basis.* The group was broken down into 9 classes, a white being graded as a 0 and the yellow parental type as an 8. For the median class, 4, a type was selected that appeared to be inter-

*At the time when these plants were being classified it was not realized that two different pigments were responsible for the yellow colour and, therefore, no attempt was made to differentiate between types on a qualitative basis.

TABLE 7.—EXPECTED AND OBSERVED SEGREGATION FOR YELLOW PIGMENT INTENSIFICATION IN DIPLOID F_2 FAMILIES

	Class									Probability value
	0	1	2	3	4	5	6	7	8	
Expected—A	0	3	9	19	23	19	9	3	0	0.2
Observed	0	2	5	17	19	23	17	2	0	
Expected—B	0	1	5	14	22	23	14	5	1	0.7

mediate between a white and a parental yellow. The result of this attempt is shown in Table 7 together with the theoretically expected values, all figures in the latter being rounded off to the nearest whole number. Two somewhat similar hypotheses were postulated to explain the observed segregation. The bases for the calculation of the expected values for hypothesis A were: *(a)* the existence of four separate loci; *(b)* complete lack of dominance; *(c)* equality of expression for all factors. Y_1Y_3, for example, was presumed to produce as much pigment as Y_1Y_1 and twice as much as Y_1 or Y_3. The field classification of this group of 85 yellow segregates was not entirely satisfactory, especially in classes 4, 5 and 6. It was felt, however, that in the extremes of the range the reliability was relatively high. The probability value for this hypothesis (A) was about 0.2.

A more complicated hypothesis, B, takes cognizance of the existence of two distinct yellow pigments in the alfalfa flowers. It is based on the assumption that the hybrid F_1 plants were heterozygous for the following five factors: *(a)* quantitative factors at two loci governing the output of one of the pigments, segregation for which would yield a ratio of 1 : 4 : 6 : 4 : 1; *(b)* qualitative factors at two separate loci of equal potency, segregation for which would yield a ratio of 1 : 6 : 9; *(c)* an intensifier factor, quantitative in inheritance, yielding a segregation ratio of 1 : 2 : 1. When these are combined they provide the expected segregation noted for hypothesis B in Table 7. The probability value of this hypothesis was 0.7.

Although the classification was arbitrary and although no progeny tests have been conducted to check the hypotheses suggested it seems logical to assume that in these diploid crosses at least four factors were involved in the production and the intensification of yellow pigmentation and that inheritance was in part quantitative and in part qualitative. Confirmation of the hypotheses suggested here depends upon the raising of a large F_3 population but the majority of the yellow segregates are self-sterile and the problem of obtaining adequate F_3 data is difficult. One of the paler of the 1951 F_2 segregates, classed as a 3, was not entirely self-sterile and yielded a progeny of seven plants consisting of three 2's, three 3's and one 4. With such limited data it would be idle to speculate on the genotype of this class 3 plant, but it is worth noting that, although it produced three plants paler than itself, none of these was in the white or near-white classes.

Segregation for Yellow Pigment in Tetraploid Families

Further information on the genetics of the yellow pigments was provided by a continuation of a study initiated by Greenshields (6). The parents used were the white-flowered plant S-42-60 and the yellow-flowered plant S-43-21. The falcata parent when selfed yielded a very uniform progeny and the F_1 population showed only a very small range of variation. These hybrid F_1 plants were intermediate in depth of colour between the white and the yellow parents. The F_2 population numbered 257 plants and consisted of three families. It was arranged into 13 classes, the white parent being ranked as a 0 and the yellow as a 12. Table 8 shows the frequency distribution of this F_2 population. No segregate was found that approximated either of the parents, although these types were discovered

TABLE 8.—THEORETICAL[1] AND OBSERVED SEGREGATION FOR YELLOW PIGMENT IN TETRAPLOID F_2 FAMILIES RESULTING FROM A WHITE X YELLOW CROSS

	Class												
	0	1	2	3	4	5	6	7	8	9	10	11	12
Expected	0	0	1	7	24	51	65	51	24	7	1	0	0
Observed	0	0	2	5	43	135[2]		28	18	2	3	0	0

[1]Assumptions made for the calculation of theoretical segregation:
(a) Three factors.
(b) Complete lack of dominance.
(c) Equality of expression for all factors.
(d) Cumulative effect.
(e) Tetrasomic inheritance.

[2]The central classes 5 and 6 constituted only one class in the actual classification in the field.

in the F_3, and the modal class corresponded in depth of yellow pigmentation to the F_1. Selected and representative F_2 plants were selfed to provide several F_3 families. Although there was here, as in the F_2, a tendency for variation to be continuous, classification was attempted and on the same basis as for the F_2. Typical frequency distribution patterns arising from some of the palest of the F_2 plants were 0-5-70-3-0 and 1-14-78-12-3, the first class in each example being a white. In the second family listed four extra plants, not there included, defied classification. They were either white or faintly ivory. The same difficulty was occasionally encountered elsewhere. In the face of such difficulties it was not found possible to postulate with confidence either the number of factor pairs segregating or the manner of segregation.

All families, whether F_2 or F_3, provided a frequency distribution that was unimodal with the mode corresponding to the median and to the type of the immediate parent. The results indicated that the yellow pigment factors followed a quantitative rather than a qualitative pattern expression and that whether inheritance was disomic or tetrasomic the yellow-flowered parent S-43-21 carried factors for yellow pigment at more than two loci.

Pigmentation Intensification Factors

The inheritance of depth of yellow and purple flower pigmentation was carefully considered. The data of the previous section indicated that production and intensity of yellow pigment were controlled by the same factors. Purple flower colour, however, is inherited differently as indicated by the variation of pigmentation of the F_1 population resulting from crosses between the four white parents referred to previously and a purple plant. Thus, progeny of S-42-60 × S-42-182 was darker than the purple parent, while that of S-42-58 × S-42-182 was much lighter. S-42-60 then, had intensification potentialities not possessed by S-42-58. In each instance intensity variability was large. In the selfed progeny of purple-flowered plants this variability was symmetrically arranged about the parent type. Diploid crosses were used to study the factors responsible for intensification.

Spectrophotometer readings were obtained on the F_1 of the purple × yellow cross S-49-154 × S-45-48. The sativa parent was estimated by comparison with standards at about 700 and the reading on the F_1 was 570. The readings for the F_2 population fell into the seven classes listed below:

Mode and range	*Frequency*
275	1
430 ± 10	2
570 ± 15	8
640 ± 25	8
740 ± 20	3
850	1
940	1

The frequency distribution indicated a quantitative relationship. The F_1 being heterozygous for C but not for P, only a small part (if indeed any) of the variability can be attributed to segregation at the C-locus. The remainder can be accounted for only by intensification factors. Since the same range of variability was found in purple × purple diploid crosses and since segregates more extreme than any of these noted above were obtained, it seems likely that depth of purple pigmentation was influenced by one or, more probably, by two intensification factors.

DISCUSSION

The object of this study was to determine whether alfalfa is an autotetraploid or an allotetraploid. In earlier studies by other workers good fits had been demonstrated to the disomic ratios of 3 : 1, 15 : 1, 63 : 1 as well as to the tetrasomic ratio of 35 : 1. In addition a number of F_2 families had segregated in the rather unusual observed ratio of about 100 : 1. To the best of the knowledge of the writer no study has yet been reported on flower colour which takes into consideration the interaction of two factors, either or both of which may show either disomic or tetrasomic segregation.

For differentiating between auto- and allotetraploidy the study of the inheritance of yellow colour was not rewarding. Both at the diploid and at the tetraploid level the number of loci was demonstrated to be at least three and more probably four and the type of expression to be largely quantitative. Since at each of the four tetraploid loci the dosage of the factor for yellow would vary from zero to four the possible number of different genotypes would be twenty. The association of a particular phenotype with a specific genotype under these circumstances is manifestly difficult and because of the arbitrary nature of the classification genetic analysis becomes unreliable. Accordingly this phase of the study shed little light on the nature of the tetraploid condition in alfalfa.

The study of the inheritance of the purple pigment was more revealing. In crosses between purple and non-purple (yellow) diploid parents segregation for purple was usually of monofactorial nature. In several crosses however, all involving the same falcata parent, complementary factors were indicated. This supposition was confirmed at the tetraploid level where certain crosses between white-flowered parents produced purple-

flowered offspring and between white-flowered and yellow-flowered parents produced purplish-yellow offspring. The inheritance of these two complementary factors might be expected to follow either of two patterns. If alfalfa is an allotetraploid disomic ratios such as 15 : 1 and 7.3 : 1 would be found for monofactorial and difactorial hybrids respectively. If, on the other hand, alfalfa is an autotetraploid the corresponding ratios would be 35 : 1 and 17.3 : 1.

In the F_2 of crosses segregating only for the factor C the evidence in favour of tetrasomic segregation was very strong. On the other hand no fixed pattern could definitely be discerned in several crosses involving the factor P. In three families segregating values were 201 : 3, 115 : 1 and 78 : 0. The sum is 394 : 4 and the probability value that this is an example of the disomic ratio 63 : 1 is 0.4. If segregation at the C-locus is tetrasomic and that at the P-locus is disomic the offspring of a dihybrid should segregate as 10 : 1. When four such dihybrids were selfed the segregation values were not significantly different at the 1 per cent level from this ratio. However, in all four families a much better fit was provided by the tetrasomic ratio 17.3 : 1.

A possible explanation of this anomaly is that segregation for the P factor is neither always disomic nor always tetrasomic but is sometimes intermediate. No white-flowered plants would be found among the offspring of a plant of genotype P′P′p″p″ CCCC if the pattern at the P-locus were disomic. If it were tetrasomic the expected number would be 1 in 36. But if P′ instead of pairing with P′ as usual, occasionally paired with p″, some gametes would carry the two recessive factors p″p″ and an occasional white-flowered plant would appear among the offspring. If, due to this semi-random type of pairing, gametes carrying the two recessive factors occurred once in ten, the F_2 ratio would be of the order of 100 : 1. It is possible that the very wide ratios such as 115 : 1 found in this study and also those reported by Armstrong and Gibson (1) had their origin in this semi-random type of pairing.

At the beginning of the "Discussion" it was stated that the object of this investigation was to determine whether alfalfa is an autotetraploid or an allotetraploid. The results of the study indicate that an unequivocal answer to the problem cannot be given. A study of the literature by Atwood and Grun (2) led these authors to the same conclusion. The evidence at present available in support of the two conflicting points of view concerning the origin of alfalfa is presented below in itemized form:

The arguments in favour of an autotetraploid origin

(1) The formation of quadrivalents at meiosis.
(2) The occurrence of tetrasomic segregation.
(3) Morphological resemblance between diploid and tetraploid plants.
(4) Morphological resemblance between natural and synthetic tetraploids.
(5) The occurrence of two satellited chromosomes in diploid material and of four in tetraploid races.
(6) The meiotic pattern of bivalent formation in a hexaploid plant, Julen (9), and in a tetraploid originating in a diploid-tetraploid cross, Ledingham (10).
(7) The high fertility of a tetraploid plant obtained in this study by a diploid-tetraploid cross (157-60 x S-43-45).
(8) The propensity of some diploid falcata plants to produce unreduced gametes.
(9) The cross-fertility of natural and synthetic tetraploids.

The arguments in favour of an allopolyploid origin

(1) The small number of quadrivalents formed at meiosis.
(2) The occurrence of disomic segregation ratios.
(3) The sterility of the haploid Grimm plant studied by Lesins (11).

Most of these items have already been noted in previous sections and no further mention will be made of them. However, a consideration of items 6, 7 and 8 may clarify some ideas not yet fully discussed.

Apparently it is not unusual for diploid falcata plants to produce unreduced gametes. Ledingham, in his cytological study of an F_1 tetraploid plant arising from a diploid × tetraploid cross, found that pairing was practically normal and resulted in the formation of 16 bivalents. Since the two sets of sativa chromosomes were either pairing with each other or with the twin sets of falcata chromosomes, those two sets must have been homologous. In the present study a similar diploid × tetraploid cross resulted in the production of a very fertile F_1 tetraploid plant. Since fertility was high, meiosis presumably was very regular. The inference from cytological and genetical data in these two similar crosses is that alfalfa originated as an autotetraploid. Nilan (13) has reported a third example of the same phenomenon. In an attempt to reconstitute the history of the variety Rhizoma he interplanted diploid falcata and tetraploid sativa plants. Among the progeny of the falcata strains used as female parents he found several tetraploids that were obviously of hybrid origin. To date no instance has been reported in the literature, to the best of the author's knowledge, of a diploid plant serving as a staminate parent in the production of a tetraploid offspring. This is not surprising since its occurrence would normally pass unnoticed.

From the investigations discussed in the previous paragraph two conclusions of immediate importance to this study may be drawn. The first is that some diploid falcata plants have within themselves a part of the potentialities necessary for the production of an autotetraploid race. The second is that in a number of instances the two sets of chromosomes in diploid gametes were homologous and that by inference the parent plant itself must have been autotetraploid.

The above discussion shows that evidence can be found to support both the autotetraploid and the allotetraploid theories on the origin of alfalfa. In the past the conflicting reports demonstrating both disomic and tetrasomic inheritance of purple flower colour have been puzzling but only so because it was not then realized that more than one factor is required for anthocyanin production. In the light of present knowledge these results are actually the ones to be expected if alfalfa originated at some period in the distant past as an autotetraploid. If this is presumed to be so there must have been since that time opportunity for protoplasmic differentiation. Probably some chromosomes, being more resistant to change than others, have retained sufficient homology to permit of random pairing and tetrasomic segregation. Others, less durable, have suffered changes in structure, perhaps through inversions, deletions, duplications or translocations, to such an extent that pairing relationships have been altered. When chromatin differentiation had progressed to the point where

synapsis between once-homologous chromosomes became difficult, evolution in any one area would favour those strains which quickly reached an harmonious readjustment whereby chromosomes synapsed by selective rather than by random pairing. Such an arrangement would result in disomic segregation, which might in turn lead to the supposition of an allotetraploid origin. But because alfalfa is a cross-pollinated crop, any individual plant may carry chromosomes which owe their origin ultimately to widely separated areas. It is to be expected that the degree of homology among those which have undergone the greatest differentiation will, in itself, be variable. The result of this is that in some plants segregation for a specific factor will be totally disomic, but that in others, partial homology between pairs may lead to a semi-random type of pairing and a segregation which is neither disomic nor tetrasomic.

The results of this study and of a perusal of the literature leads to the conclusion that alfalfa, although probably of autotetraploid origin, is now passing through a transition stage in which segregation for some factors is still tetrasomic and for others has become disomic. The type of segregation displayed for any one specific character is not constant but is a function of the degree of homology existing between the chromatin material derived from the two parental plants.

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THE REPRODUCTIVE CAPACITY OF VEGETATIVE BUDS ON THE UNDERGROUND PARTS OF LEAFY SPURGE (*EUPHORBIA ESULA* L.)[1]

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ABSTRACT

The shoots of leafy spurge usually arise from underground plant parts within a few inches of the soil surface. However, even under undisturbed conditions shoots have been found to emerge through as much as 17 in. of soil from the point of origin on the roots. Unemerged shoots originated on roots as deeply as 71 in. below the soil surface. Stands of the weed buried with as much as 3 ft. of tamped, uninfested soil are capable of producing shoots which emerge in some instances within one year after burial. Even when the root material is removed to a depth of 3 ft. and the excavation is refilled with tamped, uninfested soil, shoots emerged from below this depth to reach the surface within one year in some instances. Root material to a depth of at least 48 in. is capable of producing leafy shoots when it is placed near the soil surface. Cutting of roots stimulated the growth of buds in the region 1 to 2 in. below the cut.

INTRODUCTION

Considerable attention has been given in recent papers to the distribution of the underground parts of leafy spurge (*Euphorbia esula* L.) (1) and to the distribution of reproductive buds on these structures to depths as great as 68 inches below the soil surface (2). The ability of this perennial weedy species to produce leafy shoots from vegetative buds on the roots at considerable depths in the soil is probably a major cause of its persistence, despite vigorous attempts to control it. The depth from which reproduction can take place is undoubtedly important in relation to control by sterilization of the upper soil layers by herbicides (2) and in the survival of buried plants. The purpose of the present paper is to examine the capacity of vegetative buds to produce leafy shoots from various depths in the soil.

METHODS AND PROCEDURE

The depth of development of shoots under undisturbed conditions was examined by tracing with an ice-pick while studying bud distribution (2) and while removing monoliths for studies of root distribution (1).

The effect of burial on the development of shoots was studied by placing cribbing 1, 2 and 3 feet high above stands of the weed from which the aboveground growth had been removed. These were then filled with uninfested soil which was tamped to simulate the original soil density. The cribbing was banked on the outside with soil to offset some of the adverse environmental characteristics associated with the exposure of the cribbing and its contents above the ground level. In the first experiments the cribbing was constructed of tongue and grove lumber to enclose a plot 4 feet square. Since this did not prevent all invasion from the sides of the excavation,

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steel cribbing was later employed. This was circular in cross-section with a diameter of 22 inches (2.64 sq. ft. in area). The cribbing was open at the bottom, to permit the entrance of shoots from the original soil surface below the area enclosed, and at the top, to permit the emergence of shoots above the new soil level.

The capacity of the underground plant material to produce shoots from 1, 2 and 3 feet below the soil surface was examined by removing soil to these depths, placing the cribbing (described above) into each hole and filling with tamped, uninfested soil to the original soil level.

In order to study the capacity of roots from various depths to produce shoots when they were brought near the aerial environment, vertical slabs of soil (monoliths), which had been removed to a depth of 4 feet from infestations of leafy spurge, were placed horizontally on the soil surface. Severance of the roots at various distances below the original soil surface provided information on the effect of cutting at these levels on the production of shoots. After each cut was made, a piece of galvanized sheet iron 3.5 inches × 12 inches was inserted to prevent invasion of root material from each side. The monoliths were watered regularly to prevent desiccation.

RESULTS

Depth of Origin of Leafy Shoots Under Undisturbed Conditions

Coupland and Alex (2) have reported that the buds of leafy spurge decrease in abundance with increasing depth, being very abundant near the soil surface. By far the majority of the leafy shoots arise from the plant structures in the uppermost foot of soil. However, during the excavation of root systems of leafy spurge the authors have found numerous instances of shoots arising from buds at greater depths.

Although the deepest bud observed on the roots, which were traced from the surface, was at a depth of 68 inches (2) a shoot found in the bottom of one excavation arose from a root at 71 inches below the soil surface. This shoot was 1.75 inches long. Other shoots which were found in the same excavation originated from depths of 54, 29, 26, 24, 20 and 19 inches. The respective lengths of these shoots were 2, 1, 1, 1, 4 and 3 inches.

Although no evidence was obtained that shoots arising from depths greater than 17 inches reach the soil surface under undisturbed conditions, some unemerged shoots had developed to a considerable extent in some excavations. In one instance a shoot 6.5 inches long was produced from a depth of 47 inches, while one 14 inches long had arisen from a depth of 22 inches. The latter, although still 8 inches below the soil surface, had developed leaf scales (Figure 1). These shoots had all arisen from vertical underground structures which were apparently roots. The deepest observed origin of a shoot which had reached the surface was 17 inches. This was from a horizontal structure.

Effect of Burial on Shoot Development

The effect of burying a stand of leafy spurge with 1, 2 and 3 feet of soil was investigated in plots established in May, 1951, near Battleford and Duck Lake and others located later that year near Parkbeg, Battleford and Duck Lake. Wooden cribbing was used to enclose 16 sq. ft. in each of the

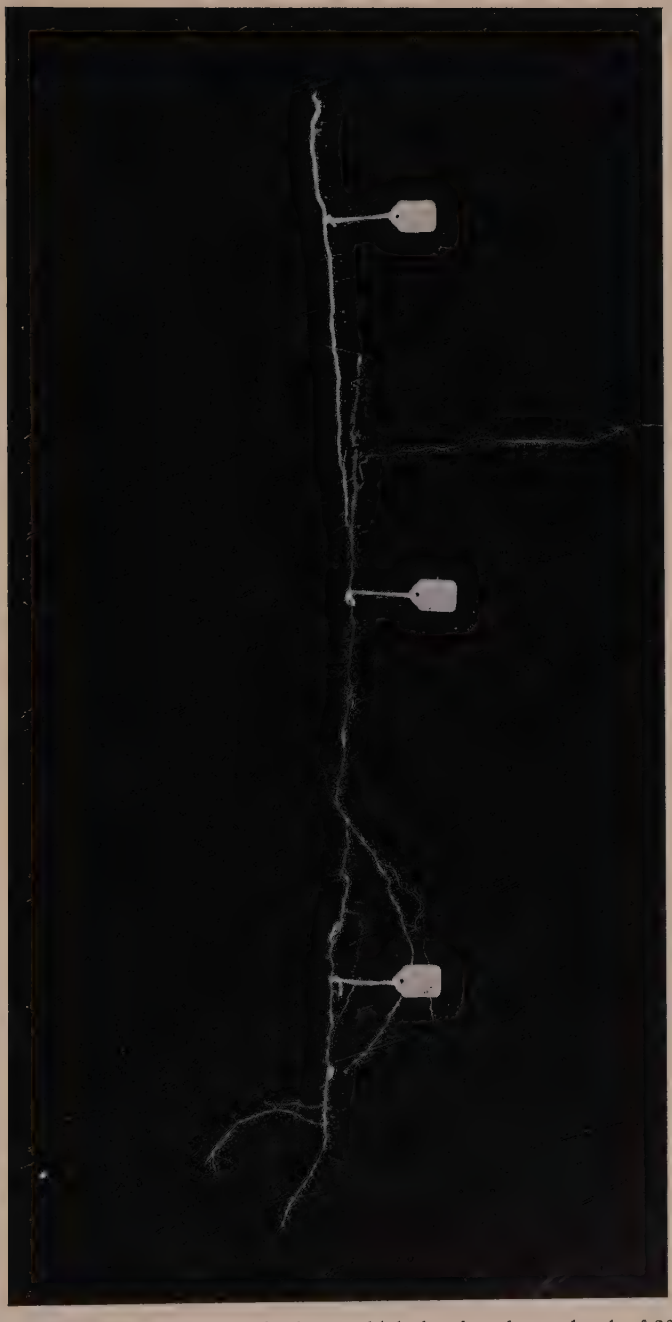

FIGURE 1. A shoot, 14 in. long, which developed at a depth of 22 in. from a vertical root of leafy spurge. The shoot was white, brittle, and had pronounced leafy scales near the tip. The tags are 12, 24 and 36 in. below the soil surface. *(Excavated and photographed August, 1950)*

FIGURE 2. Burial plots in which leafy spurge was buried with 3, 2 and 1 ft. of tamped, uninfested soil within steel cribbing banked with earth. In the foreground (obscured by vegetation) are located the plots which were excavated to a depth of 3, 2 and 1 ft. and filled with tamped, uninfested soil within steel cribbing. *(Photographed May 24, 1952)*

first set of plots at Duck Lake and Battleford. Steel cribbings (2.64 sq. ft. in cross-section) were used in all the later plots (Figure 2).

The first plots at Duck Lake were examined 133 days after establishment, at which time 108 shoots (12 of which were producing seed or had produced seed) had grown through the 12-inch plot of tamped soil. Twenty-three shoots had penetrated the soil in the 24-inch plot. No shoots had emerged at a distance greater than 12 inches inside the edges of the plot. Two shoots were in flower. In the centre of the plot the tips of the shoots were still 6 inches below the surface. No shoots had emerged above the surface of the 36-inch plot of soil, the best developed one found being 16 inches below it. The shoots in all plots were found to have arisen from plant material just below the original soil surface.

Livestock damage to the first plots at Battleford reduced the average depths of burial to 10, 19 and 29 inches but, because of the vigour of this species, emergence of shoots was apparently not affected. The numbers of shoots which had emerged through this much soil in 116 days were 29, 19 and 28, respectively. The average respective heights of the emerged shoots were 12, 10 and 6 inches.

Because the wooden cribs did not prove impenetrable to the roots of leafy spurge, steel cylinders were used in the plots established after May, 1951. These were left undisturbed for 12 months, at which time the numbers of emerged shoots were counted and in some instances the soil probed in order to establish the distance of unemerged shoots from the surface. However, the soil was replaced to make possible the examination of plots in 1953 and 1954.

TABLE 1.—NUMBERS AND HEIGHTS (IN INCHES) OF SHOOTS OF LEAFY SPURGE WHICH EMERGED AFTER BURIAL OF PLOTS (2.64 SQ. FT. IN AREA) WITH TAMPED, UNINFESTED SOIL IN 1951

Site	Advancement of shoots		Depth of soil penetrated (ft.)								
			1952			1953			1954		
			1	2	3	1	2	3	1	2	3
Duck Lake Abandoned land naturally regrassed	Flowering	No.	6	0	0	0	0	0	16	3	0
		Ht.	11	—	—	—	—	—	20	18	—
	Non-flowering	No.	26	14	0	27	10	0	8	13	24
		Ht.	5	3	—	8	7	—	12	12	10
Battleford Native grassland	Flowering	No.	8	0	0	6	28	0	28	66	1
		Ht.	17	—	—	14	18	—	28	22	25
	Non-flowering	No.	5	33	1	101	65	0	66	42	7
		Ht.	11	5	4	11	16	—	18	14	10
Parkbeg Abandoned land seeded to crested wheat grass	Flowering	No.	10	0	0	27	5	0	30	12	3
		Ht.	9	—	—	14	12	—	10	10	10
	Non-flowering	No.	28	12	1	24	37	4	17	51	6
		Ht.	4	3	0	8	8	6	6	8	8
Parkbeg Abandoned land occupied by annual weeds	Flowering	No.	2	0	0	3	0	0	13	0	0
		Ht.	14	—	—	13	—	—	12	—	—
	Non-flowering	No.	25	9	0	66	11	27	60	32	51
		Ht.	4	1	—	14	8	10	6	8	10
Mean no.	Flowering		6.5	0.0	0.0	9.0	8.2	0.0	21.8	20.2	1.0
	Non-flowering		21.0	17.0	0.5	54.5	30.8	7.8	37.8	34.5	22.0

The data obtained from these plots in 1952 are summarized in Table 1. In all instances shoots were able to emerge through 2 feet of soil in one year and to emerge through 1 foot and produce seed in one year. In half of the plots, 3 feet of soil was penetrated in one year (Figure 3). The presence of crested wheat grass (*Agropyron cristatum* (L.) Gaertn.) in the stand did not apparently reduce the reproductive capacity of roots of leafy spurge.

Numerous white, brittle shoots of leafy spurge were found to have grown within 18 inches of the surface where the weed was buried with 3 feet of soil and to within 12 inches where it was buried to a depth of 2 feet. The tips of these shoots were bent into a characteristic loop by the force exerted by the elongation of the stem. This loop straightened out after reaching the soil surface. In some instances branches occurred on the shoots below the surface (possibly a result of temporary delay in growth). Small yellowish-green leaf scales from 0.25 to 0.6 inches long and 0.06 inches wide occurred on the shoots as deeply as 18 inches beneath the soil surface. These had dried up at greater depths. Buds occurred in the axils of the leaf scales.

During the second and third year after burial the numbers of shoots emerging (Table 1) were similar in many instances to those occurring in the stand of leafy spurge which had not been buried.

Shoot Development From Roots Below Certain Depths

The capacity of root material of leafy spurge to produce shoots after the uppermost 1, 2 and 3 feet of soil was removed and replaced by tamped, uninfested soil was also measured. This was done at each of the sites at which the effect of burial was studied. After excavation of holes adjacent to the burial plots, the same type of cribbing (at first wooden, later steel) was placed in the holes and soil was tamped into them.

After 133 days, 29 shoots had emerged through 1 foot of uninfested soil in the first plots established at Duck Lake (16 sq. ft. in area). One of these was producing seed. Five shoots had penetrated 2 feet of soil (all of these being within 3 inches of the edge of the plot but arising from below the floor of the previous excavation). Several shoots occurred which had not yet reached the level of the soil surface. No shoots were encountered in the top 24 inches of tamped soil within the 3-foot excavation, the tip of the tallest being at that level. Below this depth several more were found and a large number occurred in the lower 6 inches of tamped soil.

After 116 days, 39 shoots had emerged through 1 foot of tamped soil in the 1-foot excavation in the first Battleford plots (16 sq. ft. in area). The tallest of these was 12 inches high. Two shoots had emerged in the 2-foot plot. Many more shoots had not yet emerged, these increasing in number with increased depth.

The data obtained from the smaller plots with steel cribbing are presented in Table 2. In every plot the shoots were able to emerge through 2 feet of soil and through 1 foot of soil and produce seed during the year after excavation and filling. In half of the plots a single shoot emerged through 3 feet of soil in one year. The competition of crested wheat grass did not appear to affect the capacity of the roots to reproduce. The characteristics of shoots which had not emerged were similar to those found in the plots which were buried without excavation.

TABLE 2.—NUMBERS AND HEIGHTS (IN INCHES) OF SHOOTS OF LEAFY SPURGE WHICH EMERGED AFTER EXCAVATIONS (MADE IN 1951) WERE FILLED WITH TAMPED, UNINFESTED SOIL IN PLOTS 2.64 SQ. FT. IN AREA

Site	Advancement of shoots		Depth of soil penetrated (ft.)								
			1952			1953			1954		
			1	2	3	1	2	3	1	2	3
Duck Lake Abandoned land naturally regrassed	Flowering	No.	0	0	0	0	0	0	3	1	0
		Ht.	—	—	—	—	—	—	16	24	—
	Non-flowering	No.	2	2	1	25	2	0	21	8	0
		Ht.	3	9	12	7	10	—	14	16	—
Battleford Native grassland	Flowering	No.	3	0	0	1	0	0	4	3	0
		Ht.	10	—	—	20	—	—	28	32	—
	Non-flowering	No.	54	13	1	136	55	4	131	34	5
		Ht.	9	10	0	9	10	6	17	25	12
Parkbeg Abandoned land seeded to crested wheat grass	Flowering	No.	1	0	0	7	2	0	11	3	0
		Ht.	10	—	—	15	10	—	13	13	—
	Non-flowering	No.	11	3	0	35	4	0	30	8	0
		Ht.	4	4	—	11	8	—	10	10	—
Parkbeg Abandoned land occupied by annual weeds	Flowering	No.	6	0	0	6	0	0	20	1	0
		Ht.	19	—	—	20	—	—	13	14	—
	Non-flowering	No.	20	6	0	21	14	0	41	26	0
		Ht.	10	8	—	18	10	—	11	12	—
Mean no.	Flowering		2.5	0.0	0.0	3.5	0.5	0.0	9.5	2.0	0.0
	Non-flowering		21.8	6.0	0.5	54.2	18.8	1.0	55.8	19.0	1.2

FIGURE 3. A shoot of leafy spurge which in 12 months emerged through 3 ft. of soil placed and tamped in cribbing above the soil surface. Note attachment to the old root at the base. *(Photographed on Sept. 11, 1952)*

Effect of Cutting of Underground Parts on Shoot Development

The authors have observed that one tillage operation may increase the number of leafy shoots present in a unit area of a patch of leafy spurge. This is in accord with the report of Hanson and Rudd (3) who noted that depletion of food reserves can be expected to result from such stimulation.

In order to study the effect of cutting the underground parts at various depths, monoliths 3 inches × 12 inches in cross-section were removed to a depth of 48 inches. These were placed horizontally on the soil surface within the containing boxes. Two monoliths were taken from each of eight excavations in three localities. One of each pair was cut at 12, 24 and 36 inches below the soil surface. In addition, some were cut at the 4- and 8-inch levels. The other monolith of each pair was kept as a control. The monoliths were watered regularly. This treatment began with half of the monoliths in May, 1950, and with the other half in August of the same year. Observations were made regularly until November, 1951.

The original aboveground parts continued to grow until the end of the first growing season. Leafy shoots arose from the face of the monoliths from vegetative buds on the underground parts of the plant which had been at various depths below the soil surface.

Cutting increased the number of buds produced from the 1 to 2 inches of root immediately below each cut, relative to the number produced just above each cut and to the number produced at the same level of the uncut control.

Shoots were produced on the unsectioned monoliths in greatest numbers by underground parts in the 5 inches below the original soil surface, being most frequent between 2 and 4 inches. Sectioning induced the production of a greater total number of shoots during the first season. This increase occurred primarily immediately below the cuts, since the numbers of shoots produced in other parts of cut and uncut monoliths were similar.

During the second season shoots were more abundant throughout the unsectioned blocks than they had been during the previous fall. A smaller increase occurred in the numbers of shoots which developed in the sectioned blocks.

Cutting the roots at intervals of 12 inches below the original soil surface resulted in an increase in the number of shoots produced in the surface 12-inch layer. Blocks which were cut at 4 and 8 inches below the surface (as well as at 12-inch intervals) produced a similar number of shoots in the top 12 inches during the first year but fewer during the following season.

DISCUSSION

The ability of roots of leafy spurge to produce leafy shoots from considerable depths suggests that control, to be effective, must be aimed at destruction of the roots to the depth from which these stems cannot reach the soil surface, or at producing a soil condition nearer the surface which the shoots cannot penetrate. The authors have frequently observed that intensive tillage has not been successful in starving the roots to the point of death. Hormone-like herbicides have generally been ineffective in causing more damage than decreased vigour and reduced stand. Soil sterilants have usually only temporarily prevented growth to the surface.

The capacity of the shoots to penetrate soil which has been used to bury them characterizes this species as being much more vigourous than other common perennials of this area, judging from the reports of farmers who claim to have obtained eradication of certain species (e.g. perennial sow thistle (*Sonchus arvensis* L.) and Canada thistle (*Cirsium arvense* L. (Scop.)) by this means.

The ability of the plant to produce leafy shoots from the remnants occurring after the uppermost 3 feet of underground plant material has been removed points out the fruitlessness of attempting to dig patches out. The food storage capacity below this depth is sufficient in some sites to permit the penetration of 3 feet of soil from this depth. That the food required for this growth did not come by translocation from the unexcavated part of the patch outside of the plots is indicated by the lack of horizontal underground structures below about 1.5 feet in the soil. The limitation of shoots to the proximity of the edges of some plots may be explained by the possibility that the soil was less densely tamped in that region. Some lateral translocation may have occurred in instances where burial alone was carried out or where the depth of excavation was not sufficient to sever all horizontal structures.

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THE INFLUENCE OF CERTAIN CULTURAL PRACTICES ON SOLANINE CONTENT AND TUBER YIELDS IN NETTED GEM POTATOES[1]

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ABSTRACT

The bitter flavour which sometimes occurs in Netted Gem potatoes is attributed to abnormal accumulation in the tuber of the glycoalkaloid solanine. To determine the effect of cultural practices on solanine content, plots of Netted Gem potatoes at Edmonton were subjected for two seasons to treatments that included two depths of planting, three levels of hilling, and two dates of planting with single-eye and multiple-eye seed-pieces. The differences in cultural treatment were not associated with any differences in solanine content or yield of tubers in either season. The solanine content of tuber samples collected from a fertilizer trial under irrigation at Brooks, Alberta, failed to reveal any significant effect of differences in fertilizer treatment, but a marked increase in tuber solanine occurred after a top-killing frost.

Very bitter tuber samples from several locations in Alberta contained toxic levels of solanine, but showed no greening of tubers. Investigation showed that usually one or more unfavourable environmental conditions had prevailed, such as nutritional unbalance, and frost or hail damage to the tops before tuber maturity.

In Alberta it is not uncommon for moderate to severe bitterness to be encountered in table potatoes, particularly in Netted Gem, the leading commercial variety in the Province. On occasion, this pronounced bitterness has resulted in economic loss to shippers and consumers; causal factors and possible means of control are therefore of wide concern. The bitter agent has been established to be the complex glycoalkaloid solanine and its alkaloid solanidine, and published research reports on factors causing abnormally high concentrations in potato tubers are frequently contradictory or inconclusive.

REVIEW OF LITERATURE

It has been established that the high concentration of solanine that imparts a bitter flavour to potato tubers (6, 22, 24) may, if ingested, cause symptoms of sore throat, illness (1, 3, 5, 12), and occasionally even death (11). The bitter flavour has been thought to be associated with sunburn or greening from exposure to light (4, 14). However, Wolf and Duggar (25), as well as Dabbs and Hilton (9), have established that tubers frequently may contain toxic concentrations of solanine without any evidence of greening or other tissue discoloration, although most sunburned tubers are also high in the glycoalkaloid.

The family *Solanaceae*, to which the potato belongs, is noted for the many alkaloids found in its various species; for example, nicotine in *Nicotiania* spp., and hyocyamine in *Atropa belladonna* L. (19). Solanine of the

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potato (*Solanum tuberosum* L.) is a complex glycoalkaloid, which on acid hydrolysis liberates one molecule each of dextrose, rhamnose and galactose, leaving the alkaloid base solanidine (10, 12, 25) and possibly another alkaloid solanthrene (24, 25). The latter compound may be a product of solanine decomposition, rather than a naturally occurring alkaloid. The properties of solanine have been investigated by a number of workers (8, 23, 24, 25) and compiled by several authors (3, 10, 12). Complete agreement does not exist regarding its structural formula (7, 10, 25). The taste of solanine is somewhat bitter and pungent, leaving in the pharynx a persistently acrid sensation.

Wolf and Duggar (25) found the solanine content of 17 potato varieties to range from 1.8 to 13 mg. per 100 gm. fresh weight, depending upon the variety. The normal range reported by most previous workers (5, 13, 20, 22) falls within these limits. Bömer and Mattis (5) reported that 20 mg. per 100 gm. fresh weight is the upper limit of safety for food. Unripe tubers are generally reported to have a higher solanine content than mature ones (15, 20), and small tubers to have a higher solanine content than large ones (5, 15, 20). In spite of the obvious relationship between planting date, tuber size and tuber maturity, Braun (6) reported that no correlation between solanine content and planting date could be demonstrated. Arutyunyan (2) claimed that the solanine content of potatoes is greater when grown in hot climates, but that summer cultivation reduces it. Potatoes with high solanine content, used as seed, have been found to produce tubers of normal solanine content (5, 12), though an instance is recorded where it was said that two seasons were required before the proportion reached normal levels (13). The solanine content of potato tubers increases when they are exposed to daylight (20), sunshine (10, 19), or ultra-violet light (2, 8). Green or sunburned potatoes have been reported to have 55.7 to 58.8 mg. solanine per 100 gm. fresh weight (10, 15). Immature potatoes show increases in solanine upon exposure to light, while old potatoes do not (5). Connor (8) exposed potato tubers to different wave lengths of light. He found that ultra-violet rays of about 300 mμ were most effective for solanine formation but did not cause greening. The yellow-red end of the spectrum caused greening but did not result in significant increases in solanine. Mayfield (18) noted that Netted Gem potatoes stored in a cool, damp cellar developed a greenish-yellow colour accompanied by an acrid flavour, even in the absence of light.

Wolf and Duggar (25) reported that solanine synthesis in the growing shoot with an adequate supply of carbohydrates is apparently independent of light, but that light affects its distribution. Plants grown under long-day conditions tend to have more solanine, with the greater concentration being found in the tops. Highest concentrations of solanine occur in those organs and tissue where metabolic activity is greatest (13, 25).

Reports on the effects of the major elements, moisture and organic content of the soil on solanine content of potatoes are conflicting (20, 21), some claiming no effect (5, 6, 15). Gortner (10) believes that the alkaloid content of plants may be increased or decreased by appropriate selection of strains, by plant breeding and by fertilization. In support of this, he cites the nicotine content of tobacco as an instance of an alkaloid that has

been increased by plant breeding and manuring. Moreover, Loustalot and Winters (16, 17) found that the alkaloid content of the roots and stems of *Cinchona ledgeriana* was highest with high nitrogen levels in the soil, and was significantly greatest under conditions of medium and high soil moisture.

EXPERIMENTAL

To study the effects of certain cultural practices on the amounts of solanine occurring in Netted Gem potatoes, two factorial field experiments were conducted in three replicates in 1950 and again in 1951. The two experiments were laid out side by side in one block with the rows running north and south. Replicates were placed end to end and numbered from south to north. Split-plot designs were used and treatments applied for one experiment included normal and late planting as main plots, with single-eye and multiple-eye seed-pieces as sub-plots. In the other trial, deep and shallow planting treatments (2.5 and 5.0 inches) were the main plots, and sub-plot treatments were three levels of hilling (high, low and none). Each sub-plot consisted of three rows, 30 feet long and 36 inches apart. At harvest, yield data and sample tubers for solanine analysis were taken from the centre row after the end hills had been discarded. About 25 tubers, ranging in size from 3 ounces upwards, were taken at random from the dug row, placed in cotton sacks and promptly stored in total darkness in a cool root cellar. From these, 6 or 7 washed tubers of representative sizes were macerated (peel included) in a Waring Blendor, after a brief storage period, and quick-frozen until solanine analyses could be performed. In this way it was felt that storage effects would not complicate cultural effects.

During the course of these investigations, samples of bitter and non-bitter Netted Gem tubers were also secured from representative areas throughout the Province of Alberta. In addition, samples of Netted Gem potatoes were collected and quick-frozen from a potato fertilizer experiment under irrigation at the Provincial Horticultural Station, Brooks, Alberta. The trial was of randomized block design and the treatments were 11-48-0 at 200 lb. per acre, 11-48-0 at 200 lb. per acre plus manure, and a control, each in three replicates. The soil is a brown sandy loam, and had produced alfalfa during the two previous seasons, and the potato crop received two irrigations during the season. The quadruplicate samples from each replicate were analysed in February, 1952, after being quick-frozen in macerated form just after harvest.

A different method was used each of the two years to extract solanine from the quick-frozen samples, but the same colorimetric method was used each year for its estimation. The cold ethanol extraction method of Rooke *et al.* (23) was used on duplicate 150-gm. samples of the 1950 crop. However, instead of adding a solubility correction factor to the solanine precipitated, as did Rooke and co-workers (23) and most previous workers (5, 13, 20, 22), the filtrate was adjusted to a pH of 10.2 – 10.4 before precipitation, according to the method of Wolf and Duggar (25), who showed that solanine is insoluble in aqueous solutions above pH of 9.3. This method of precipitating the solanine from an alkaline solution was used on both the 1950 and 1951 samples.

In 1951, duplicate solanine extractions were made on the quick-frozen 25-gm. samples of minced tuber material which were a composite of seven tubers randomly sampled from each 30-foot treatment row. The recently reported Soxhlet extraction method of Dabbs and Hilton (9), which utilizes acidified ethanol, was applied to the 1951 samples. It reduced the extraction time and gave very satisfactory results.

Solanine concentrations were estimated colorimetrically with a Fisher Electrophotometer from a 0.5 per cent acetic acid solution of the final precipitate after the method of Pfankuch (22) as modified by Wolf and Duggar (25). Readings were taken after a time interval of 45 to 55 minutes, using filter 525 mμ.

TABLE 1.—SOLANINE CONCENTRATIONS IN NETTED GEM POTATOES; 1950 AND 1951 CULTURAL TRIALS

Treatment	Solanine in mg. per 100 gm. fresh weight*	
	1950	1951
Shallow planting	4.8	8.7
Deep planting	4.7	8.0
High hilling	4.0	7.9
Low hilling	4.6	7.7
No hilling	5.5	9.4
Normal planting	8.5	8.8
Late planting	5.6	8.0
Single-eye pieces	6.7	8.4
Multiple-eye pieces	7.6	8.5
Mean	5.8	8.4

*A different analytical procedure was used in each year *(see text)*. In 1950 the number of determinations per treatment was variable, from a low of 13 (low hilling) to a high of 26 (late planting) and totalling 172. In 1951, 4 determinations were made from each replicate in each trial.

TABLE 2.—SOLANINE IN 1951 NETTED GEM POTATOES FROM SHALLOW AND DEEP PLANTING WITH HIGH, LOW AND NO HILLING. DATA IN MG. SOLANINE PER 100 GM. FRESH WEIGHT

Planting depth	Hilling	Replicates*			Treatment means
		I	II	III	
Shallow	High	3.3	7.7	13.0	8.0
	Low	3.8	5.1	14.0	7.5
	None	5.8	9.3	16.3	10.5
Deep	High	6.6	7.4	9.4	7.8
	Low	5.7	5.6	12.2	7.8
	None	3.9	5.0	15.9	8.3

*Differences between replicates significant at the 5 per cent level.

RESULTS AND DISCUSSION

The results of the analyses for solanine concentrations from the cultural trials conducted in 1950 and 1951 are summarized in Table 1. There were no significant differences in solanine concentrations between treatments. There was, however, a high replicate variance for solanine concentrations in both experiments in the 1951 season, reaching the significant level in the experiment on the effects of depth of planting and hilling (see Table 2). The reason for this difference between replicates remains obscure. It may be attributable to soil variability, although differences in soil topography were not obvious. The previous production history of the land area involved is not recorded, but it is known that the soil was used in the production of a large number of crop kinds, in connection with vegetable trials. No differences in tuber yields between replicates were found.

Certain other trends in the solanine and tuber yield data for the two years were more or less consistent but were not significant. These are as follows: (1) Late planting (June 9-10) resulted in a lower tuber yield and a lower solanine concentration than normal planting (May 18-20); and (2) solanine content was slightly higher in tubers receiving no hilling, but tuber yields were not influenced by hilling. No trends were apparent for the other factors studied.

The fertilizer trial at the Alberta Horticultural Station, Brooks, has been described earlier in this paper as a randomized block design utilizing commercial fertilizer and manure, alone and in combination. The tuber samples drawn from this experiment were analysed for solanine content and the results are summarized in Table 3. An analysis of variance revealed no significant treatment effects, but in spite of this the variability between treatments is such that it would seem desirable further to investigate the influence of potato plant nutrition on solanine content.

The cultural factors studied do not appear to have as great an effect on the occurrence of solanine in the tubers as do other conditions of the environment. This conclusion is based upon the results reported above, and observations made during two widely different growing seasons—the summer of 1950 having been very dry, that of 1951 unusually wet. In neither year did samples from the experimental plots contain abnormal amounts of solanine.

TABLE 3.—SOLANINE CONCENTRATION IN NETTED GEM TUBERS, BROOKS FERTILIZER TRIAL. DATA IN MG. SOLANINE PER 100 GM. FRESH WEIGHT

Treatment	Replicates			Means
	I	II	III	
1. 11-48-0 at 200 lb./A.	8.7	8.8	9.1	8.9
2. As (1), plus 10 tons manure	9.1	5.4	11.4	8.6
3. Check	10.9	11.2	5.2	9.1
Means	9.6	8.5	8.6	8.9

There is some circumstantial evidence to suggest that damage of the potato tops by hail or summer frosts increases the incidence of solanine in the Netted Gem variety. Frequently, when the history of a bitter sample is investigated, it is found that one or both of these phenomena are involved. In 1951, samples of Netted Gem potatoes were dug at weekly intervals at Edmonton from September 3 to October 1 and analysed for solanine. Little or no solanine was found until after a night frost had severely damaged the tops on September 24. Solanine per 100 gm. fresh weight, which had ranged from 0 to 1.2 mg. before the frost, increased to a range of 3.6 to 6.7 mg.

Certain factors of the environment during the growth and maturing periods of potato tubers appear to produce physiological imbalances that are the cause of, or coincident with, high solanine build-up in the tubers. These factors may be: the duration and intensity of sunlight on plant tops and on the soil over the tubers; damage to plants by frost and hail; temperatures during tuber-setting and tuber-maturing periods; exposure of tubers to direct sunlight during harvesting operations; and the physical and chemical nature of the soil. Studies on these aspects of the problem are being undertaken.

It is the writers' belief that solanine bitterness may be likened to or even classed as a non-parasitic physiological disorder, to which the Netted Gem variety is susceptible. Sunburn with its attendant greening need not be present, since dangerously high solanine concentrations occasionally occur in Netted Gem potatoes that are of excellent appearance.

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GROWTH AND YIELD OF McINTOSH APPLE SCIONS AS INFLUENCED BY THE USE OF VARIOUS ROOTSTOCK-INTERSTOCK VARIETAL COMBINATIONS[1]

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ABSTRACT

A field experiment with top-worked apple trees was conducted over a 13-year period in order to study the effects upon the scion variety, McIntosh, of the three rootstock varieties Malling I, Malling II and Antonovka, and the two interstock varieties Osman Crab and Hibernal. These were included in all possible combinations of a rootstock variety with an interstock variety.

The data concerning widths of crowns, heights, and trunk circumferences are indicative of uniformity with respect to size and general conformation. The widths and heights of the experimental trees lay within ranges which approximated those for standard McIntosh trees of the same age. However, the differences between width and height tended to be greater in the case of the latter than in the case of the experimental trees.

The scion: interstock circumference ratio was always less than 1 in the case of trees with the interstock variety Hibernal, and always greater than 1 in the case of trees with the interstock variety Osman Crab. There was no relationship between the ratio and the yielding ability of the scion.

The yield of trees upon the semi-dwarfing rootstock variety Malling II was significantly greater than the yield of trees upon the vigour inducing rootstock variety Malling I. Neither interstock nor the interaction between rootstock and interstock had a significant effect upon yield.

INTRODUCTION

It is thought that apple trees which are smaller at maturity than those developed upon French Crab seedling roots may lower orchard costs. Relative to this, orchard research, at present, is concentrated to a considerable extent upon efforts to develop smaller apple trees. Furthermore, in the colder parts of Canada, including the Province of Quebec, a hardier framework is a present need because trunk and branch crotches are the tree parts which most often suffer from winter injury during severe seasons. In connection with these problems a study of the general field of stock-scion relationships has proven profitable.

A considerable amount of research has been done with the purpose of determining the influences exerted individually by certain varieties of apple rootstock or interstock upon scion varieties. Less consideration has been given to the effects of different varietal combinations of root and interstock upon scion varieties. Therefore, the field experiment described in this paper was carried out in order to study the effects of certain rootstock-interstock combinations upon the growth and yield of the scion variety McIntosh, and to directly evaluate the worth of these combinations in the development of winter hardy apple trees of less than standard size.

In accordance with the distinction made by Hewetson (2), a top-worked interstock is here considered to be one which forms the framework of the tree, whereas a double-worked interstock forms only the trunk of the tree.

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METHODS

The plant materials which were used in this experiment were supplied by the Division of Horticulture, Canada Department of Agriculture, Central Experimental Farm, Ottawa. The rootstock varieties were Malling I, Malling II, and Antonovka. According to the classification made by Hatton (1), Malling I is a vigorous stock, and Malling II is a semi-dwarfing stock. Antonovka may be termed semi-vigorous. It has proven to be compatible with a wide range of commercial varieties. Furthermore, it appears to be highly resistant to collar rot. The cold-resistant varieties Osman Crab and Hibernal were used as interstocks. They, also, are compatible with a large number of commercial varieties. The scion variety which was used, namely, McIntosh, may be termed semi-vigorous.

The interstock varieties were bench-grafted to the rootstock varieties to form six rootstock-interstock varietal combinations, namely, Antonovka/Osman Crab, Malling I/Osman Crab, Malling II/Osman Crab, Antonovka/Hibernal, Malling I/Hibernal, and Malling II/Hibernal. The trees thus formed were set out as 2-year olds at Macdonald College during the spring of 1940. Each rootstock-interstock combination was replicated eight times. Each tree was top-worked to the scion variety, McIntosh, which was cleft-grafted upon the interstocks in early spring during the years 1943, 1944, and 1945. The design was factorial with 48 experimental apple trees arranged in 8 randomized blocks of 6 plots (trees) each. The experimental block was enclosed by 36 non-experimental guard trees of McIntosh and/or Melba top-worked to the variety Hibernal on Siberian Crab (*Malus baccata*) root systems. The spacing distances for both experimental and non-experimental trees were 20 feet between trees in the row, and 18 feet between rows.

TABLE 1.—MEAN MONTHLY MAXIMUM AND MINIMUM TEMPERATURES IN DEGREES F. FOR THE PERIOD 1940 TO 1953, INCLUSIVE

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean maximum	43.0	40.4	52.5	69.1	79.2	88.9	90.7	88.7	84.2	75.2	62.7	45.9
Mean minimum	−16.0	−15.0	− 6.7	22.0	32.2	35.5	47.7	44.5	31.7	26.0	11.5	−12.6
Lowest recorded	−23.0	−27.0	−19.0	14.0	27.0	32.0	42.0	39.0	28.0	21.0	− 2.0	−25.0

TABLE 2.—MEAN MONTHLY AND ANNUAL PRECIPITATION IN INCHES[1] FOR THE PERIOD 1940 TO 1953, INCLUSIVE

Mean monthly precipitation												Mean annual precipitation
Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
2.85	2.56	3.11	3.13	3.01	3.04	4.05	3.40	3.08	3.06	3.53	3.46	38.42

[1] The density of the snow not being available, 10 inches of snow is equated to 1 inch of rain.

The soil of the experimental plot may be classified, in general, as a Potsdam sandstone moraine loam with a tendency to high lime subsoil. Determinations of the soil reaction, at various depths within a surface layer 18 inches thick, have indicated a pH range of 6.5 to 7.

Clean cultivation was practised until August, 1950, when a sod-mulch system of culture described by Palmer and Haarlem (4) was commenced. The area was sown to a mixture of Orchard grass and Kentucky bluegrass. Ammonium nitrate was applied at the rate of one-eighth of a pound per year of tree age to each tree just as growth was beginning each spring. At the same time, each year, the grass was given a general application of 9-5-7 fertilizer at the rate of 300 pounds per acre.

Standard spray programs were followed with the result that the trees were free from diseases and insect troubles.

Prior to the spring of 1952, pruning was confined to light thinning. In 1951 the trees became overcrowded because of the narrow spacing. In the springs of 1952 and 1953 this condition was alleviated, temporarily, by lightly cutting back the lateral growth.

Data were recorded concerning precipitation, temperatures, growth and yields.

The experiment was terminated in December, 1953. Certain trees were removed so that those remaining were arranged according to the quincunx system. The roots of the removed trees were exposed for examination. The soil was pushed back from the trunks of the remaining trees in order to determine if self-rooting had occurred.

RESULTS AND DISCUSSION

The results set forth here represent the performance of the experimental apple trees through 13 years in the orchard. It is suggested that the relative positions of the various experimental combinations with respect to tree size and yielding ability (see Tables 3, 4, 5, and 6) may not represent

TABLE 3.—HEIGHTS AND CROWN EXPANSES IN FEET OF TOP-WORKED APPLE TREES, DECEMBER 1, 1953

Block and tree number	Rootstock-interstock											
	M.I[1]				Ant.				M.II			
	O.C.		Hib.		O.C.		Hib.		O.C.		Hib.	
	Ht.[2]	C.E.[2]	Ht.	C.E.	Ht.	C.E.	Ht.	C.E.	Ht.	C.E.	Ht.	C.E.
1	13.5	15.5	12.2	14.2	13.2	14.9	11.9	13.0	12.9	14.0	13.0	14.5
2	12.0	14.0	13.5	14.5	—[3]	—	13.2	14.9	12.5	13.5	12.9	14.2
3	13.2	15.2	12.0	13.9	13.0	14.5	11.2	12.2	11.0	12.5	11.9	13.0
4	13.0	15.0	13.0	14.0	12.9	14.0	13.2	14.5	12.9	13.9	—[3]	—
5	13.5	15.0	12.5	13.5	11.2	12.5	13.0	14.2	11.0	12.0	11.0	12.5
6	11.0	12.0	13.0	15.0	13.2	14.9	11.9	13.2	13.0	15.0	12.9	14.5
7	13.2	15.0	13.4	15.2	13.2	14.5	13.0	15.0	13.5	14.9	12.5	13.5
Mean	12.8	14.5	12.8	14.3	12.8	14.2	12.5	13.9	12.4	13.7	12.4	13.7

[1] M.I, Malling I; M.II, Malling II; Ant., Antonovka; O.C., Osman Crab; Hib., Hibernal.
[2] Ht., Height; C.E., Crown Expanse.
[3] See following section (*Missing Trees and Hardiness*).

the relative positions of older trees in the same varietal combinations. It has been clearly recognized by Hewetson (3) that the performance of a scion variety upon a particular rootstock-interstock varietal combination is often closely associated with the age of the tree.

Missing Trees and Hardiness

In the presentation of data (see Tables 3, 4, 5, and 6) five trees are treated as missing plots. The growth of one of these, in the series Antonovka/Osman Crab, was greatly retarded because of mechanical injury. Two trees were found to be self-rooted. One of these was in the series Malling I/Osman Crab, and the other in the series Antonovka/Hibernal. Two trees, one in the series Malling I/Hibernal, and one in the series Malling II/Hibernal, died as a result of frost injury to their root systems. These losses occurred in 1942 and 1949, respectively.

There were three trees missing from Block 8, namely, the two self-rooted trees and one of the dead trees. Therefore, this block was omitted from the statistical analysis of the data in order to increase the accuracy of the results. The number of missing plots were thus reduced to two. The analyses of variance were carried out according to a method described by Yates (6).

No inferences can be drawn respecting rootstock hardiness on the basis of the observed frost injury which occurred in two rootstock varieties, but in only two trees. It was observed, however, that the close spacing of the trees resulted in the retention of relatively heavy protective snow coverings over their roots. It is considered that this factor sometimes enables relatively tender root systems to survive severe cold. Nevertheless, the fact that 46 of the experimental trees survived for 13 years indicates that the three experimental rootstock varieties exhibited a considerable degree of hardiness under the test conditions.

TABLE 4.—TRUNK CIRCUMFERENCES[1] IN INCHES OF THE INTERSTOCKS OF TOP-WORKED APPLE TREES

Block and tree number	Rootstock-interstock											
	M.I[2]				Ant.				M.II			
	O.C. 1949	O.C. 1953	Hib. 1949	Hib. 1953	O.C. 1949	O.C. 1953	Hib. 1949	Hib. 1953	O.C. 1949	O.C. 1953	Hib. 1949	Hib. 1953
1	9.8	18.5	7.6	13.1	13.1	21.0	10.7	18.3	13.0	19.1	10.6	15.1
2	11.8	21.8	8.7	17.4	—[3]	—	13.1	20.0	13.8	22.5	14.1	22.3
3	12.2	21.4	13.6	22.3	11.3	19.0	12.3	19.4	8.6	14.0	13.2	19.9
4	13.5	22.5	11.5	18.2	9.6	16.5	10.2	17.4	11.7	19.5	—[3]	—
5	9.7	18.3	13.3	17.8	10.7	17.8	13.6	21.0	11.0	19.5	13.3	21.0
6	11.7	21.8	12.2	17.8	11.2	19.1	13.1	18.8	12.1	21.0	12.1	18.8
7	5.8	10.3	13.5	20.0	11.3	18.0	10.1	16.9	12.5	18.9	11.8	18.5
Mean	10.9	19.2	11.5	18.1	11.2	18.6	11.9	18.8	11.8	19.2	12.5	19.3

[1] Measurements taken at 1 foot above ground level.
[2] M.I, Malling I; M.II, Malling II; Ant., Antonovka; O.C., Osman Crab; Hib., Hibernal.
[3] See above section (*Missing Trees and Hardiness*).

TABLE 5.—SCION: INTERSTOCK CIRCUMFERENCE RATIOS[1] OF TOP-WORKED APPLE TREES

Block and tree number	Rootstock-interstock					
	M.I.[2]		Ant.		M.II	
	O.C.	Hib.	O.C.	Hib.	O.C.	Hib.
1	1.098	0.964	1.159	0.915	1.042	0.987
2	1.081	0.945	—[3]	0.962	1.127	0.887
3	1.340	0.962	1.155	0.952	1.035	0.935
4	1.036	0.955	1.039	0.897	1.021	—[3]
5	1.124	0.928	1.040	0.972	1.143	0.928
6	1.072	0.915	1.145	0.943	1.053	0.927
7	1.060	0.960	1.101	0.877	1.126	0.930
Mean of series	1.119	0.947	1.107	0.931	1.078	0.932

[1] The recorded data are the means of the ratios of the three lower branches of each tree.
[2] M.I, Malling I; M.II, Malling II; Ant., Antonovka; O.C., Osman Crab; Hib., Hibernal.
[3] See preceding section (*Missing Trees and Hardiness*).

Data relating to the temperatures and precipitation which occurred during the experimental period are presented in Tables 1 and 2. There appears to be no clear relationship between these data and yields and/or vegetative growth. However, this information possesses value in that it is partially indicative of the adaptability to climate of the various varieties in the experimental combinations. It is evident that widely fluctuating temperatures occurred in all months. Fluctuations of this kind occurring during late winter or early spring are especially unfavourable for fruit trees. It will be seen that the precipitation exhibited a relatively even distribution. Rain or snow fell in each month.

Vegetative Growth

Height and expanse of crown. The experimental trees were remarkably uniform with respect to their heights and crown expanses. Data recorded December 1, 1953 (see Table 3) show that the heights and crown expanses lay within the ranges 11 to 13.5 feet and 12 to 15.5, respectively. These ranges approximated those for standard McIntosh trees, on French Crab seedling rootstocks, developed in the Macdonald College orchard to the same age as the experimental trees. However, within the limits of these ranges, the widths of the experimental trees tended to be from 1 to 2 feet greater than their heights, whereas the widths of the standard McIntosh trees tended to be from 2 to 4 feet greater than their heights. A probable explanation of this may lie in the close spacing of the experimental trees which may have resulted in an increased rate of growth upwards towards the light. It is apparent from the foregoing data that, under the test conditions, none of the six rootstock-interstock varietal combinations, each top-worked to the scion variety McIntosh, resulted in a tree smaller than standard size. It is also apparent that the data given in Table 3 bear no relationship to yields (see Table 6).

TABLE 6.—TOTAL YIELDS OF APPLES IN POUNDS PER TREE FOR THE PERIOD 1947 TO 1953, INCLUSIVE

Block and tree number	Rootstock-interstock					
	M.I.[1]		Ant.		M.II	
	O.C.	Hib.	O.C.	Hib.	O.C.	Hib.
1	354	205	772	745	661	524
2	678	161	—[2]	631	613	924
3	439	690	587	488	469	1,346
4	863	312	314	535	832	—[2]
5	450	997	754	752	655	982
6	725	982	585	1,003	824	956
7	298	709	611	482	673	652
Completed total series	3,807	4,056	4,146.4	4,636	4,727	6,235.3
Mean	543.9	579.4	592.3	662.3	675.3	890.8
Completed total, rootstock	7,863		8,782.4		10,962.3[3]	
Mean	561.6		627.3		783[4]	

[1] M.I, Malling I; M. II, Malling II; Ant., Antonovka; O.C., Osman Crab; Hib., Hibernal.
[2] See Table 3.
[3] Least significant difference (5 per cent level) between totals, 2,388.17.
[4] Least significant difference (5 per cent level) between means, 180.26.

Trunk circumferences. The trunk circumference of each experimental tree was taken in inches, at one foot above the ground level, on the first of June during each of the years 1949 to 1953, inclusive. Data pertaining to these measurements are given for the years 1949 and 1953 in Table 4. These data are without significance. There is no relationship between them and yields (see Table 6). The variability in trunk circumference within each series was considerable. This result suggests that variability in trunk size was not reduced by the use of clonal rootstocks in preference to seedling rootstocks. It will be seen, however, that there are no marked differences between the six series means shown for each year in Table 4.

Scion: interstock circumference ratio. Soon after the experimental trees were top-worked to the scion variety McIntosh it was observed that consistent growth rate differentials existed at all graft unions. It was decided to express these numerically in an effort to determine their meaning. Accordingly, the scion: interstock circumference ratios of the three lower branches of each tree were determined on June 1, 1953. The means of these ratios, for each tree, are recorded in Table 5. A ratio less than 1 indicates that the scion was smaller than the interstock, whereas a ratio greater than 1 indicates scion overgrowth.

The tops of the trees were remarkably uniform in size irrespective of the values of the growth ratios at the graft unions. Further, there is no relationship between the data recorded in Table 5 and the data respecting yields (see Table 6). It will be noted that the ratio was less than 1 for every tree in which the variety Hibernal formed the interstock, and that the ratio was greater than 1 for every tree in which the variety Osman Crab formed the interstock. Thus, the scion: interstock circumference ratio appears to be an expression of an effect of the variety employed as an interstock, namely, Hibernal or Osman Crab. The expression of this effect is not indicative of tree stature or of yielding ability.

Yield of Fruit

The general initation of bearing occurred in 1947. However, one-half of the trees in each of the rootstock-interstock combinations Malling I/ Osman Crab, and Antonovka/Osman Crab did not bear until 1948. The yield of each tree was recorded annually. Table 6 gives the total yields in pounds per tree and per series for the period 1947 to 1953, inclusive. The analysis of variance derived from the missing plot-technique described by Yates (6) is set up in Table 7.

The analysis of variance of the data set forth in Table 6 shows that the yield of trees upon the rootstock variety Malling II was significantly greater at the 5 per cent level than the yield of trees upon the rootstock variety Malling I. Neither the interstock nor the interaction between the rootstock and the interstock had a significant effect upon yield. These results are in accordance with certain findings reported by Upshall (5) to the extent that he found, on a per tree basis, that the yield of the variety McIntosh upon Malling II roots exceeded that of McIntosh upon Malling I roots. However, the yield differences reported by Upshall were not significant.

TABLE 7.—ANALYSIS OF VARIANCE OF TOTAL YIELDS OF APPLES IN POUNDS PER TREE FOR THE PERIOD 1947 TO 1953, INCLUSIVE

(Derived from missing-plot technique)

Factor	Sum of squares	Degrees of freedom	Variance
Total	2,427,057.98	39	
Blocks	444,173.97	6	
Rootstock	362,117.16	2	181,058.58*
Interstock	120,203.80	1	120,203.80
Interaction: Rootstock × interstock	63,701.77	2	31,850.88
Error	1,436,861.28	28	51,316.47

* Significant at the 5 per cent level.

An examination of Table 6 reveals that the yields of the varietal combinations, from least to greatest, are ranged in the order Malling I/Osman Crab, Malling I/Hibernal, Antonovka/Osman Crab, Antonovka/Hibernal, Malling II/Osman Crab, and Malling II/Hibernal. This order of yield appears to the authors to be of considerable interest, despite the fact that there are no significant differences between the six totals. These results appear to suggest that the yielding ability of the scion variety, McIntosh, has not only been influenced by the root stock varieties Malling I, Antonovka, and Malling II in the order named, but that the effects of each rootstock have been modified by the effects of the interstock variety Osman Crab and/or the interstock variety Hibernal. In the case of each of the three rootstock varieties in combination with the interstock variety Hibernal, or the interstock variety Osman Crab, the greater yield of the scion variety McIntosh was produced when the interstock variety was Hibernal.

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GENESIS AND MORPHOLOGY OF THE ONEIDA AND HALDIMAND SERIES—GREY-BROWN PODZOLIC SOILS IN ONTARIO[1]

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ABSTRACT

The pH, bulk density, organic matter content, cation exchange capacity, and exchangeable cations of genetic horizons of four Oneida profiles and three Haldimand profiles were found to be similar. The clay content of the B and C horizons in the Haldimand soils was much higher than in comparable horizons in the Oneida soils although the texture of the A horizons was similar in all soils. Chemical analysis of the whole soils and of the 0.25 to 1 mm. sand fraction showed that the Haldimand soils were developed partially from stone free overwash and partially from much finer clay or till. The Oneida soils were found to be developed from a uniform till deposit.

INTRODUCTION

In order to define a series and to support the field separation of two similar series it is desirable, and indeed often necessary, to determine certain physical and chemical characteristic of representative soils in the laboratory.

The objectives of this study were (1) to characterize the Oneida and Haldimand series as representatives of the Grey-Brown Podzolic soils in Ontario; (2) to determine certain physical and chemical characteristics of the Oneida and Haldimand series as they are mapped in Peel, Lincoln, and Haldimand Counties, and (3) to determine additional differences between the two series in support of the field separations.

DESCRIPTION OF SOILS

The observable characteristics of the profiles of the Oneida and Haldimand series are common to many Grey-Brown Podzolic soils in Ontario. The soils resemble the central concept of the Grey-Brown Podzolic great soil group described by Baldwin (1) except that they have two sub-divisions of the A_2 horizon. Cline (6) has described the A_{21} and A_{22} horizons as being characteristic of modal Grey-Brown Podzolic soils in New York.

The Oneida series occupies about 168,000 acres and the Haldimand series more than 350,000 acres in Southern Ontario, mainly around the western end of Lake Ontario and along the Lake Erie shore.

The entire area is underlain by Paleozoic sedimentary strata. The bedrock in the Peel County area from which the soil samples were taken is shale of the Queenston formation (3). In the Lincoln County area, the bedrock is Lockport and Guelph dolomite and in the Haldimand County area it is Onondaga limestone (3).

[1] Taken in part from theses submitted to the Graduate School, University of Toronto, by the junior authors in partial fulfilment of the requirements for the degrees of Master of Science in Agriculture.

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TABLE 1.—LOCATIONS OF THE PROFILES SAMPLED

Profile number	Series name	County	Township	Concession	Lot
1	Oneida	Peel	Chinguacousy	III E	21
2	Oneida	Peel	Toronto	I W	4
3	Oneida	Lincoln	Grimsby	IV	5
4	Haldimand	Haldimand	Cayuga	V	20
5	Haldimand	Lincoln	Grimsby	IX	10
6	Oneida	Lincoln	Clinton	VI	17
7	Haldimand	Lincoln	Gainsborough	VI	5

The Oneida soils have developed on a fluted till plain in Peel County and on the "Vinemount Moraine" (5) in Lincoln County. The "Haldimand Clay Plains" (5) south of the Vinemount Moraine have given rise to the Haldimand soils. One of the Oneida profiles included in this study has been studied previously (11).

Seven sites were selected in unpastured woodlots. Four of the profiles represented the Oneida series and three profiles represented the Haldimand series. The locations of the profiles are described in Table 1. Oneida profile number 2 has been described in detail by Reid and Matthews (11) and a generalized description of the Oneida series is given below (9):

A_0 —Thin layer of partially decomposed leaves, twigs, etc.

A_1 —0-5 inches silt loam; very dark greyish brown (10 YR 3/2)*; fine granular structure; few stones; pH 5.6.

A_{21}—5-12 inches clay loam; yellowish brown (10 YR 5/4); weak platy structure; stonefree; pH 5.4.

A_{22}—12-15 inches clay loam; brownish yellow (10 YR 6/6); weak platy structure; stonefree; pH 5.5.

B_2 —15-28 inches clay; dark brown (10 YR 4/3); coarse blocky structure; few stones; pH 6.4.

B_3 —28-32 inches clay; pale brown (10 YR 6/3); weak blocky structure; few stones; pH 6.9.

C —Clay till; pale brown (10 YR 6/3); prismatic structure; calcareous; stony; pH 8.0.

* Munsell colour notation.

The following is a generalized description of the Haldimand series as mapped in Lincoln and Haldimand Counties:

A_0 —Thin layer of partially decomposed leaves, twigs, etc.

A_1 —0-3 inches silty clay loam; dark grey (10 YR 4/1); fine crumb structure; stonefree; pH 5.5.

A_{21}—3-7 inches clay loam; light yellowish brown (10 YR 6/4); weakly developed platy structure; stonefree; pH 5.0.

A_{22}—7-10 inches clay loam; very pale brown (10 YR 7/3); platy structure; stonefree; pH 5.0.

B_1 —10-12 inches clay; pale brown (10 YR 6/3); medium blocky structure; stonefree or some grit; pH 5.9.

B_2 —12-20 inches clay; dark brown (10 YR 4/3); coarse blocky structure; some mottling; stonefree to gritty; pH 6.9.

C —Grey (10 YR 6/1) clay; calcareous; some grit and small stones; pH 8.0.

EXPERIMENTAL METHODS

Samples were taken from the central part of each genetic horizon delineated on the sides of freshly dug pits. All soils were sampled to a depth of 45 inches. The samples were air-dried, ground and passed through a 2-mm. sieve. The fractions passing the sieve were stored in moisture cans in a desiccator. Core samples for bulk density determination were taken by driving a core sampler horizontally into the central part of each horizon. The soil cores were dried and the bulk density was calculated. Bulk density determinations of each horizon of each profile were made in triplicate.

Mechanical analyses were made in duplicate by the hydrometer method (2). The organic matter of the surface horizons was destroyed in a muffle furnace before analysis was made. The pH values were determined potentiometrically with the glass electrode in a 1 : 1 suspension of soil and water.

The cation exchange capacity was determined by the neutral normal ammonium acetate method as described by Peech (10). Calcium and magnesium in the ammonium acetate extract were determined by the versenate method as described by Cheng and Bray (4). Potassium and sodium were determined with the Beckman flame photometer.

Total carbonates were determined by the Schollenberger method (12) and organic carbon was determined by Walkley's modification of the Schollenberger method (13). Organic matter was calculated by multiplying the per cent organic carbon by the factor 1.724.

Total analysis was carried out according to the methods described by Hillebrand and Lundell (8).

RESULTS AND DISCUSSION

The data of this study are presented as means by genetic horizons for each of the two series. The data for the Oneida series represent four profiles and those for the Haldimand series represent three profiles.

The mean particle size distribution and standard deviations of genetic horizons of Oneida and Haldimand series are shown in Table 2. In the Oneida series, a clay maximum was evident in the B_3 horizon. This horizon, therefore, should be designated as a B_{22} horizon. A previous study (11) indicated that clay ($<0.5\mu$) was translocated from the A_2 to B horizons by genetic processes. The Haldimand soils, however, showed no well defined clay maximum in the profile. There was, however, a sharp increase in clay content at an average depth of ten inches below the surface. This increase roughly corresponded to the change from A_{22} to B_1 horizon and the content of clay continued to increase gradually with depth down to the C_1

TABLE 2.—MEAN PARTICLE-SIZE DISTRIBUTION AND STANDARD DEVIATIONS OF GENETIC HORIZONS OF PROFILES GROUPED ACCORDING TO SERIES

Horizon	Sand	S.D.	Silt	S.D.	Clay	S.D.
			Oneida			
	%		%		%	
A_1	25.5	1.71	52.2	4.18	22.3	4.48
A_{21}	26.9	8.58	45.3	3.29	27.3	5.17
A_{22}	26.7	7.97	47.0	3.64	28.7	2.99
B_1	25.3	8.49	37.9	5.30	36.8	11.27
B_2	21.9	7.09	33.6	5.36	44.4	10.22
B_3	10.2	6.84	34.9	3.29	54.9	8.89
C′	22.3	6.68	32.3	2.94	45.9	9.54
C″	21.2	5.25	38.6	3.05	40.2	6.52
C‴	21.5	5.31	37.7	3.25	40.8	6.24
			Haldimand			
	%		%		%	
A_1	21.1	5.45	51.6	3.82	27.5	6.88
A_{21}	23.6	6.15	45.6	6.65	30.7	8.02
A_{22}	22.8	5.02	44.6	7.03	32.5	7.60
B_1	16.7	5.32	38.2	10.25	45.0	14.60
B_2	17.1	2.95	24.5	2.90	68.6	5.20
C′	3.1	6.74	24.8	6.14	72.0	6.45
C″	1.7	2.32	32.4	5.92	71.5	6.21
C‴	0.8	1.45	40.5	5.84	66.3	6.50
C⁗	0.9	1.02	40.8	6.01	64.7	6.35

horizon. The relatively great difference in texture between the A_{22} horizon (32.5 per cent clay) and the B_2 (68.6 per cent clay) was probably not due entirely to processes of soil genesis, but may be due to differences in the parent material of the two horizons.

The texture of the A horizons of both series was quite similar but the Haldimand sub-soil horizons were much finer in texture than those of the Oneida series.

TABLE 3.—MEAN ORGANIC MATTER CONTENT AND STANDARD DEVIATIONS OF GENETIC HORIZONS OF PROFILES GROUPED ACCORDING TO SERIES

Oneida			Haldimand		
Horizon	O.M.	S.D.	Horizon	O.M.	S.D.
	%			%	
A_0	24.49	14.64	—	—	—
A_1	6.06	1.26	A_1	16.60	9.28
A_{21}	3.44	0.58	A_{21}	3.49	0.69
A_{22}	1.95	0.33	A_{22}	2.09	0.01
B_1	0.69	0.27	B_1	1.45	0.26
B_2	0.52	0.12	B_2	0.96	0.09
B_3	0.62	0.14	C′	0.53	0.15
C′	0.34	0.16	C″	0.26	0.12
C″	0.28	0.12	C‴	0.25	0.10
C‴	0.28	0.10	C⁗	0.25	0.10

The average organic matter contents of genetic horizons of each series are shown in Table 3. Variations in organic matter among soil profiles of the same series were relatively large particularly in the surface horizons and in the C horizons. No consistent significant differences between series were evident either in total organic matter content or in its distribution. At one of the sampling sites for the Haldimand soil, there was a thick grass sod and no A_0 horizon was evident. This accounts for the relatively high average organic matter content of the A_1 horizon of the Haldimand soils. The average organic matter content of the A_0 and A_1 horizons of the Oneida soils was almost equal that of the A_1 of the Haldimand soils. In soils of both series, the A_{21} horizons contained more organic matter than the A_{22} horizons.

The mean bulk density of comparable horizons of the two series were quite similar, as shown in Table 4, although the C horizons of the Oneida soils had a greater average bulk density than the C horizons of the Haldimand soils, presumably as a result of the lower clay content of the former. In both series, the average bulk density increased gradually with depth in the profile. One of the Oneida soils, however, that was a relatively strongly developed Grey-Brown Podzolic soil had a maximum bulk density in the B horizon. The bulk density increased sharply from the A_1 horizon, where organic matter concentration was highest, to the A_{21} horizon in soils of both series.

The cation exchange capacity, shown in Table 5, was highest in the A_1 horizons of both series because of the high organic matter concentration. A second maximum in exchange capacity was evident in the B horizons of both series. The cation exchange capacity of the A_{21} horizons was greater

TABLE 4.—MEAN AND STANDARD DEVIATION OF BULK DENSITY OF GENETIC HORIZONS OF ONEIDA AND HALDIMAND PROFILES

Oneida			Haldimand		
Horizon	Mean	S.D.	Horizon	Mean	S.D.
	gm./cc.			gm./cc.	
A_1	0.66	0.02	A_1	0.64	—
A_{21}	1.05	0.10	A_{21}	1.12	0.09
A_{22}	1.25	0.11	A_{22}	1.25	0.22
B_1	1.40	0.51	B_1	1.41	0.17
B_2	1.54	0.12	B_2	1.46	0.72
B_3	1.42	0.15	—	—	—
C′	1.67	0.21	C′	1.56	0.43
C″	1.68	0.19	C″	1.56	0.44
C‴	1.68	0.19	C‴	1.56	0.40

TABLE 5.—MEAN AND STANDARD DEVIATION OF pH AND CATION EXCHANGE CAPACITY BY GENETIC HORIZONS OF ONEIDA AND HALDIMAND SERIES

Horizon	Oneida				Haldimand			
	pH		Cation exchange capacity		pH		Cation exchange capacity	
	Mean	S.D.	m.e./100 gm.		Mean	S.D.	m.e./100 gm.	
			Mean	S.D.			Mean	S.D.
A_1	5.6	0.50	43.72	18.60	5.3	0.52	41.05	7.49
A_{21}	5.0	0.68	13.99	1.50	4.9	0.98	14.05	2.72
A_{22}	4.9	1.16	10.72	1.39	5.1	1.05	12.63	2.91
B_1	5.8	0.79	12.59	5.81	5.1	0.73	14.50	4.98
B_2	6.3	1.06	14.45	2.74	6.0	0.85	24.30	3.12
B_3	7.3	0.98	16.50	4.52	—	—	—	—
C′	8.0	0.00	10.30	6.52	8.0	0.00	13.56	1.14
C″	8.0	0.00	11.05	5.26	8.0	0.00	13.25	3.05
C‴	8.0	0.00	10.92	6.21	8.0	0.00	12.98	2.56

than that of the A_{22} horizons also because of the slightly higher organic matter content of the former horizons. The variations in exchange capacity of some soil horizons within the same series were relatively large, coefficients of variability ranging up to 50 per cent of the mean in some instances.

TABLE 6.—MEAN AND STANDARD DEVIATION OF EXCHANGEABLE CATIONS OF GENETIC HORIZONS OF ONEIDA AND HALDIMAND SERIES

Horizon	Ca		Mg		K		Na	
	m.e./100 gm.		m.e./100 gm.		m.e./100 gm.		m.e./100 gm.	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Oneida								
A_1	21.25	6.41	3.93	2.77	0.65	0.52	0.10	0.03
A_{21}	2.55	1.31	0.73	0.31	0.17	0.12	0.10	0.04
A_{22}	2.29	0.84	0.64	0.26	0.16	0.11	0.06	0.02
B_1	7.63	3.37	0.98	0.27	0.16	0.05	0.11	0.05
B_2	15.41	6.90	2.12	1.11	0.18	0.08	0.15	0.04
C′	27.19	3.41	1.81	1.23	0.16	0.08	0.14	0.07
C″	28.23	3.52	1.83	1.13	0.16	0.08	0.14	0.07
C‴	28.49	4.20	1.91	1.15	0.16	0.08	0.14	0.04
Haldimand								
A_1	19.89	1.34	4.46	2.16	0.51	0.17	0.13	0.06
A_{21}	2.82	1.95	0.69	0.44	0.12	0.04	0.07	0.02
A_{22}	1.58	0.35	0.97	0.46	0.15	0.07	0.14	0.03
B_1	3.15	0.62	1.81	1.30	0.19	0.02	0.16	0.05
B_2	13.94	2.51	7.46	4.88	0.33	0.09	0.31	0.17
C′	27.24	4.12	7.18	4.75	0.24	0.05	0.45	0.37
C″	27.52	3.92	7.08	4.20	0.24	0.04	0.43	0.31
C‴	27.45	3.92	7.12	3.93	0.24	0.04	0.42	0.31

The reaction of comparable horizons, also shown in Table 5, was similar for the two series studied. The A_2 horizons had the lowest pH and the C horizons of both series had a pH of 8.0. The C horizons of the Oneida soils contained 15 $\pm$ 4 per cent calcium carbonate equivalent compared to 20 $\pm$ 5 per cent calcium carbonate equivalent in the C horizons of the Haldimand soils.

The pH of soil is related to its percentage base saturation. The exchangeable calcium content, shown in Table 6, was relatively high in the A_1 horizons of both series because of the high cation exchange capacity and the return of calcium in the leaf litter. This was also true but to a lesser extent, for exchangeable magnesium, potassium, and sodium. There was a sharp decrease in exchangeable bases in the A_{21} and A_{22} horizons and then an increase through the B horizons to 100 per cent base saturation in

the C horizon. The content of exchangeable magnesium, potassium and sodium, was appreciably higher in the C horizon of the Haldimand than in the C horizon of the Oneida series. The standard deviations reported along with the mean values indicate a relatively wide range in amounts of the different exchangeable cations in horizons of the same series.

A fusion analysis was made of Haldimand profile number 4 for comparison with Oneida profile number 2 analysed previously (11). The data

TABLE 7.—CHEMICAL ANALYSIS OF HALDIMAND SOIL PROFILE NUMBER 4

Horizon	Element						
	SiO_2	R_2O_3	Fe_2O_3	Al_2O_3*	$CaCO_3$ equivalent	Organic matter	$\frac{SiO_2}{R_2O_3}$
	%	%	%	%	%	%	
A_1	63.65	13.34	3.09	10.24	0.0	12.58	2.13
A_{21}	73.15	16.32	3.98	12.33	0.0	3.40	2.00
A_{22}	69.60	19.33	5.14	14.19	0.0	2.10	1.62
B_2	58.69	26.80	7.24	19.56	0.11	0.90	0.99
C 20″-30″	53.57	24.76	6.77	17.99	17.30	0.61	0.97
C 30″-36″	44.27	20.93	5.80	15.13	22.75	0.52	0.95
C 36″-42″	41.81	18.88	5.20	13.65	24.59	0.50	1.01
C 42″-45″	42.80	19.41	5.43	13.98	24.46	0.50	1.00

* Includes TiO_2.

TABLE 8.—CHEMICAL ANALYSIS OF ONEIDA SOIL PROFILE NUMBER 2 (11)

Horizon	Element						
	SiO_2	R_2O_3	Fe_2O_3	Al_2O_3*	$CaCO_3$ equivalent	Organic matter	$\frac{SiO_2}{R_2O_3}$
	%	%	%	%	%	%	
A_1	56.71	12.04	2.91	9.13	0.0	22.58	1.62
A_{21}	74.43	15.08	3.69	11.39	0.0	2.55	1.69
A_{22}	72.20	17.07	4.38	12.69	0.0	1.55	1.46
B_1	66.80	21.15	6.16	14.99	0.0	0.87	1.10
B_2	63.69	23.06	6.79	16.27	0.05	0.62	0.96
C 28″-37″	51.38	17.45	4.92	12.53	10.12	0.28	1.02
C 37″-41″	46.56	15.98	4.57	11.41	12.20	0.28	1.02
C 41″-45″	46.11	15.99	4.49	11.50	12.14	0.28	1.00

* Includes TiO_2.

in Tables 7 and 8 show an accumulation of sesquioxides in the B horizons of each soil. Moreover the A_{22} horizons had a higher percentage of iron and alumina than the A_{21} horizons. Lime had been removed to a mean depth of 20 inches in Haldimand profile and 29 inches in the Oneida profile. There was a gradual decrease in per cent silica from the A_{21} horizon down to the C horizon in both soils. The chemical make-up of the C horizon of the Haldimand soil was similar to that of the C horizon of the Oneida soil except that the former had a higher lime content.

In spite of the fact that the chemical data for the Haldimand soil profiles are similar to those for the Oneida soils which have developed from a uniform till deposit (11), the great decrease in particle size from the A_{22} to B_1 horizon of the Haldimand soil compared to the decrease from A_{22} to B horizon of the Oneida soil suggested non-uniformity of the material from which the Haldimand profile developed. It is impossible to account for the large loss, by genetic processes, of clay necessary to develop the silt loam A horizons from the fine clay material of the C horizon in the Haldimand profile.

It has been postulated by Reid and Matthews (11) that the 0.25 to 1 mm. sand fraction has not weathered appreciably during the development of Ontario soils. The chemical analysis of this particular fraction of sand from each horizon of the profile, therefore, should be the same if all horizons were developed from the same kind of parent material.

The chemical analysis of the 0.25 to 1 mm. fraction of sand from Haldimand profile number 4 is presented in Table 9. There was a sharp decrease in the amount of this fraction present in the B horizon compared to the A horizons. Moreover, there was a decrease in the percentage of SiO_2 in the 20-30 inch layer compared to the layers above. In this layer

TABLE 9.—CHEMICAL ANALYSES OF 0.25 TO 1 MM. SAND FRACTION OF HALDIMAND PROFILE 4

Horizon	Per cent of whole oil	SiO_2	R_2O_3	Fe_2O_3	Al_2O_3	CaO	MgO	$\frac{SiO_2}{R_2O_3}$
		%	%	%	%	%	%	
A_1	6.9	85.1	10.6	2.2	8.4	1.6	0.9	1.91
A_{21}	10.45	80.9	9.8	2.1	7.7	1.8	0.8	1.95
A_{22}	7.53	81.1	11.2	2.1	9.1	1.5	0.8	1.69
B_1	2.19	80.5	12.7	2.7	10.0	1.2	0.8	1.50
B_2	1.17	80.3	14.8	2.6	12.2	1.4	0.8	1.26
C 20″-30″	0.92	76.8	18.4	5.2	13.2	1.3	1.4	1.00
C 30″-36″	0.45	76.9	17.9	5.2	12.7	1.5	2.8	1.02
C 36″-42″	0.14	73.7	18.4	6.1	12.3	1.6	3.2	1.02
C 42″-45″	0.09	73.9	17.6	5.9	11.7	1.7	2.5	1.04

also there was twice as much iron as in any horizon above. The SiO_2: R_2O_3 ratio of 1.00 for the 20-30 inch layer compared to the ratio of 1.26 for the horizon above also indicates a major change in parent material. The per cent MgO in the layers below 20 inches was nearly three times that in the horizons above 20 inches.

CONCLUSIONS

In so far as the chemical data are concerned, the soils of the Oneida and Haldimand series are not significantly different from other Grey-Brown Podzolic soils studied in Ontario. The pH of the solums of these soils, however, is more acid, by about one pH unit, than most of the Grey-Brown Podzolic soils in Ontario.

The clay maximum in the B horizon of the Oneida series is also typical of Grey-Brown Podzolic soils. The Haldimand soils also had a sharp increase of clay in the B horizon over the A_{22} horizon but the clay content continued to increase down to the C_1 horizon. Although it was probable that some clay had accumulated in the B horizon from the horizons above, it was equally apparent that there was a major change in kind of parent material at an average depth of ten inches. It was concluded that the Haldimand soils used in this study had developed partly in a stone free silty clay loam or silt loam overwash underlain by a calcareous, gritty, fine clay sediment. Field examination of Haldimand soil areas subsequent to the completion of this study has revealed profiles that have developed entirely in the stone free overwash as well as profiles that have less than 6 inches of overwash.

It was concluded that the pale brown colour of the A_{21} horizon of the Haldimand as well as the Oneida soils was due to finely divided organic matter probably as coatings on the mineral grains. Otherwise, the A_{21} horizons were similar to the A_{22} horizons although the latter contained a slightly greater percentage of sesquioxides in both soils.

The differentiation of the Oneida and Haldimand soils at the series level is valid. The Oneida soils developed from a relatively uniform glacial clay till deposit. The Haldimand soils, however, developed from non-uniform materials because there is no evidence of sufficient clay movement in the profile to account for the development of the silt loam A horizons from material as fine in texture as the underlying material. Moreover, the differences between the chemical analyses of the 0.25 to 1 mm. sand fraction from the A horizons and from the B horizons of the Haldimand profile indicated non-uniformity of the original soil material.

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NOTE ON ALCOHOLIC FERMENTATION IN THE STOMACHS OF LAMBS FED HIGH-GLUCOSE DIETS[1]

Previous work (1, 2) indicated that suckling lambs, goats and calves would not survive on fat-free diets consisting of glucose, casein, minerals and vitamins. The symptoms of listlessness, leg weakness, staggering and muscular twitching were prevented or cured by adding either lard or hydrogenated coconut oil to the diet.

In a recent experiment with 15 lambs, 8 per cent lactose and 8 per cent glucose were compared in a 13.5 per cent solids milk to determine if the carbohydrate fraction of the diet was responsible for the condition. Three per cent lard replaced an equal weight of glucose in a control diet.

One lamb receiving the fat-free glucose diet died in 6 days. Its stomach contents smelled strongly of alcohol and ingesta withdrawn by stomach tube from remaining lambs reached alcohol concentrations of up to 0.616 per cent. Urine alcohol of these lambs was then checked daily and just prior to death the concentrations varied from 0.205 to 0.524 per cent. Blood alcohol content of severely affected lambs varied from 0.303 to 0.455 per cent. Alcohol was not detected in the blood, urine or stomach contents of the lambs fed lactose. Controls receiving glucose plus lard occasionally had alcohol in their stomachs, blood, and urine, (maximum of 0.157, 0.180 and 0.259 per cent respectively) but these levels were never maintained for more than one or two days. Agar plate counts of stomach samples indicated that the alcohol resulted from a bacterial rather than from a yeast type of glucose fermentation observed with pigs (3, 4). Cultures of stomach organisms produced large quantities of alcohol when grown *in vitro* on a glucose-casein medium but yielded no alcohol on a lactose-casein medium. The addition of lard to the glucose medium did not restrict the amount of alcohol produced in six days' incubation.

Alcohol intoxication was artificially induced in 4 lambs on the lactose and control diets by adding absolute alcohol to the diet at the rate of 10 ml. per kilogram of body weight for one day or 5 ml./kg./day for five days. When the blood and urine alcohol concentrations reached approximately 0.450 per cent, the lambs showed symptoms identical to those produced by the fat-free glucose diet.

The fact that significant quantities of alcohol were produced from time to time in lambs on the control diet suggests that, in experiments conducted with similar diets, the results may be influenced by the occurrence of undetected alcoholic fermentation.

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